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TECHNICAL REPORT

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U.S. ARMY TARADCOM

PARAMETRIC ENGINEERING SYSTEM DEFINITION MODEL

VOLUME I

MAIN REPORT, APPENDICES A AND B

July 1979

Contract DAAK30-78-C-0059

by S. Spaulding, A. Weintraub,
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U.S. ARMY TANK-AUTOMOTIVE
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FOREWORD

This document is the final report of work accomplished by Vector Research, Incorporated, (VRI), for the US Army Tank-Automotive Research and Development Command under Contract No. DAAK30-78-C-0059. Under this contract, VRI has developed a parametric engineering system definition model which can be used by the TARADCOM Plans and Operations Office to (1) define the "parametric" configuration of advanced concept vehicles and (2) drive a life-cycle cost model which will estimate R&D, acquisition and operating and support costs of the concept vehicle. The following VRI personnel have contributed significantly to the development of the model described in this report:

S.L. Spaulding (Project Leader)

A.C. Weintraub

F.A. Cioch

J.E. Lenz

The project staff wishes to acknowledge the valuable contribution to this project of Dr. Paul C. Glance of the TARADCOM Plans and Operations Office and of many other members of the TARADCOM staff. The project staff has drawn heavily on the expertise in combat vehicle planning and design available within TARADCOM.

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EXHIBITS

EXHIBITS

(Concluded)

1.0 INTRODUCTION AND OBJECTIVE

The Parametric Engineering System Definition Model described in this report was developed by Vector Research, Incorporated (VRI) as a planning tool for the U.S. Army Tank Automotive Research and Development Command (TARADCOM).

Exhibit 1 indicates where this model will fit within the "hierarchy of models" which can be used for the evaluation of R&D program alternatives in areas of TARADCOM responsibilities.

1.1 Purpose of the Model

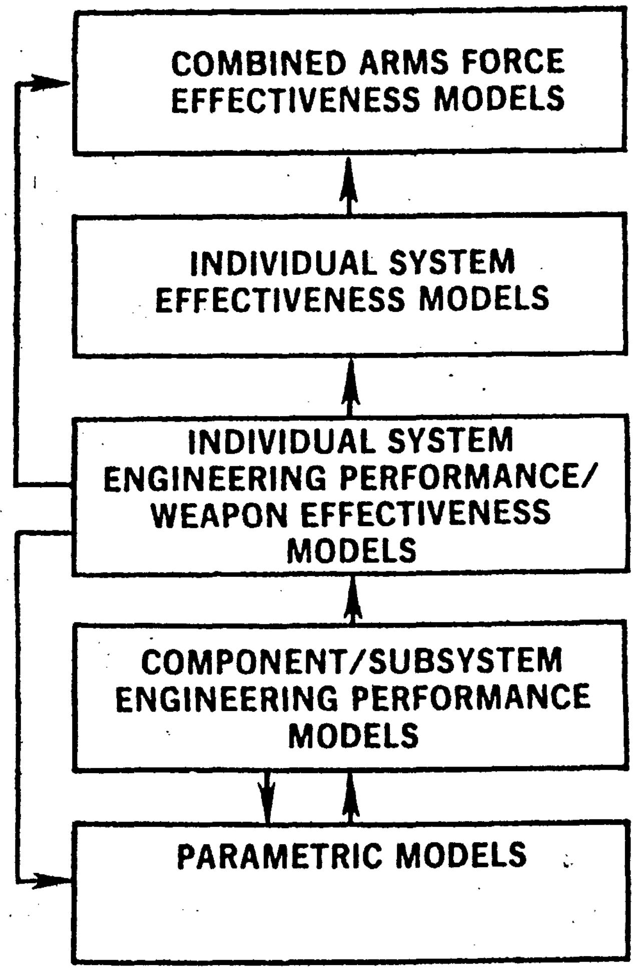
The general purpose of the model is to estimate the size, general configuration, and approximate performance of conceptual armored combat vehicles based on a small set of key parameters specified by the model user. The model is intended to be used in conjunction with a parametric life cycle cost estimating model under development by TARADCOM. Together these models can be used in planning the future armored combat vehicle fleet and evaluating alternative R&D programs to support development of future armored combat vehicles.

1.2 Potential Uses of the Model

Potential uses of the model include:

(1) Estimation of armored combat system performance which could be expected for a given set of components. Components specified

EXHIBIT 1: HIERARCHY OF MODELS



EXAMPLES

- CARMONETTE - HIGH RESOLUTION BATTALION LEVEL MODEL
- DYNTACS
- BLDM

- SURVIVABILITY OPTIMIZATION MODEL

- AMM-74 MOBILITY MODEL
- TACOME 3 ARMOR MODEL

- TRACK DYNAMICS MODEL
- TACOME 2 ARMOR MODEL

- LCC PARAMETRIC MODEL
- PARAMETRIC ENGINEERING DEFINITION MODEL

may be various combinations of:

- Fully developed components of currently field or developmental systems,
- Developmental component incorporated current state-of the-art technology, and
- Conceptual components incorporating projected future state-of-the-art technology.

(2) "Sizing" a vehicle to meet a set of performance specifications. For this type of use the model can:

- Indicate the feasibility of the specifications,
- Select a set of components and generate estimates of major engineering characteristics for the system, and
- Provide inputs to the Parametric Life Cycle Cost Model.

1.3 General Modeling Approach

In deciding upon the general approach to the design of the model, VRI reviewed previous work in the area of estimating required system engineering characteristics (e.g. gross vehicle weight, gross horsepower, vehicle size, etc.) based on performance specifications. Previous work reviewed included the following:

- The Philco-Ford Aeronautics Division Study, *Application of Trade-Off Methods to Armored Vehicle Design Evaluation* [Owen, et al, 1963].

- The Lockheed Missiles and Space Company Study, *Parametric Design/Cost Effectiveness Study* [Lockheed, 1965].
- Work done by the Systems Research Group of the Ohio State University on "Design Models" as part of the multi-year study, *The Tank Weapon System* [Bishop and Stollmack, 1968].
- *The MBT-70 Productibility/Cost Reduction (PCR) Study* [Battelle, 1969]
- A linear programming model for use in making design trade-offs developed by A. Newell at TACOM [Newell, 1969].
- The HESCOMP Model for "sizing" and performance estimating of conceptual helicopters developed by Boeing Vertol [Davis and Wisnieswski, 1974].

The Philco-Ford and Lockheed efforts developed a variety of linear statistical regression relationships between system engineering parameters and system performance characteristics, e.g. required power loading (horsepower per ton) as a function of required speed and slope performance (e.g. required speed on 10% grade.) The work of Newell used these linear relationships in a mathematical programming formulation intended for use in making design trade-offs. The Ohio State work included a "Hardware Interaction Model" for estimating structual dimensions and weights which accounted for the geometry of the components incorporated in the vehicle. The HESCOMP model is cited as an example of a model with a similar purpose to the one described here, but for helicopter systems instead of armored combat vehicles.

After reviewing the work cited above and discussing the problem with knowledgeable personnel at TARADCOM, VRI selected the following approach:

- Configure a data base structure to contain descriptions of components which might be incorporated into future armored combat vehicles.
- Make use of a combinational algorithm called "backtracking" to search over alternative combinations of components to find one which meets the specifications input by the model user.
- Implement the OSU "Hardware Interaction" algorithm for estimation of resultant overall dimensions and weights based on space requirements and weights of crew and components selected.
- Design algorithms for estimating system performance using outputs produced by TARADCOM system performance models in the form of "look-up" tables. (Note that in exhibit 1 arrows are shown indicating these models furnishing inputs to the Parametric Models.)

The rationale for selection of this approach may be summarized as follows:

- The approach accounts for the discrete nature of most major com-components, such as the main gun, engine and transmission.
- The "look-up" table format for functional relationships used to estimate performance has the following advantages:
    - it is more general in form than the linear regression relationships used in some of the earlier work, e.g., [Owen, *et al*, 1963] and [Lockheed, 1965]. (Some relationships may be inherently non-linear.);
    - it facilitates refining the functional relationships, i.e., by simply updating the data base; and

- it exploits outputs of TARADCOM system performance models, e.g., the Power Train Model, the V-Ride model, the TACOME models, etc.

- The approach provides considerable flexibility in inputting specifications for concept vehicles.
- The basic structure of the model is designed to facilitate making future refinement. (This is achieved in part through a flexible list structure for internal data storage.)

1.4 *Outline of the Remainder of Report*

The remainder of this report is organized as follows:

- Chapter 2 describes the operation of the model,
- Chapter 3 provides instruction for using the model,
- Chapter 4 discusses model test run results,
- Appendix A contains a list of references,
- Appendix B contains a description of the OSU "Hardware Interaction" Model, and
- Appendix C (Volume II) contains the FORTRAN listing of the program.

2.0 DESCRIPTION OF MODEL OPERATION

Chapter 1 discussed the general approach to the development of the model. This chapter describes the operation of the model. Section 2.1 discusses the overall model structure. Section 2.2 discusses inputs supplied by the model user. Section 2.3 outlines the structure of the model data base. Section 2.4 discusses the input routines and the internal data structure. Section 2.5 describes the operation of the solution algorithm, and section 2.6 discusses estimation of system engineering and performance characteristics. The output routines are discussed in section 2.7.

2.1 Overall Model Structure

Exhibit 2 is a schematic of the overall structure of this model. The major components of this structure are:

- a small set of user input specifications for the conceptual vehicle;
- a data base containing descriptions of components from which a concept vehicle can be generated;
- a set of input processing routines for reading user specifications and portions of the data base and for storing these inputs in an internal data structure which will be referenced by the solution routine;
- a set of solution routines which generate a concept vehicle to meet the user specifications (or to indicate that the specifications are infeasible.); and
- a set of output routines for displaying the characteristics of the generated concept vehicle and the components used.

EXHIBIT 2: OVERALL MODEL STRUCTURE

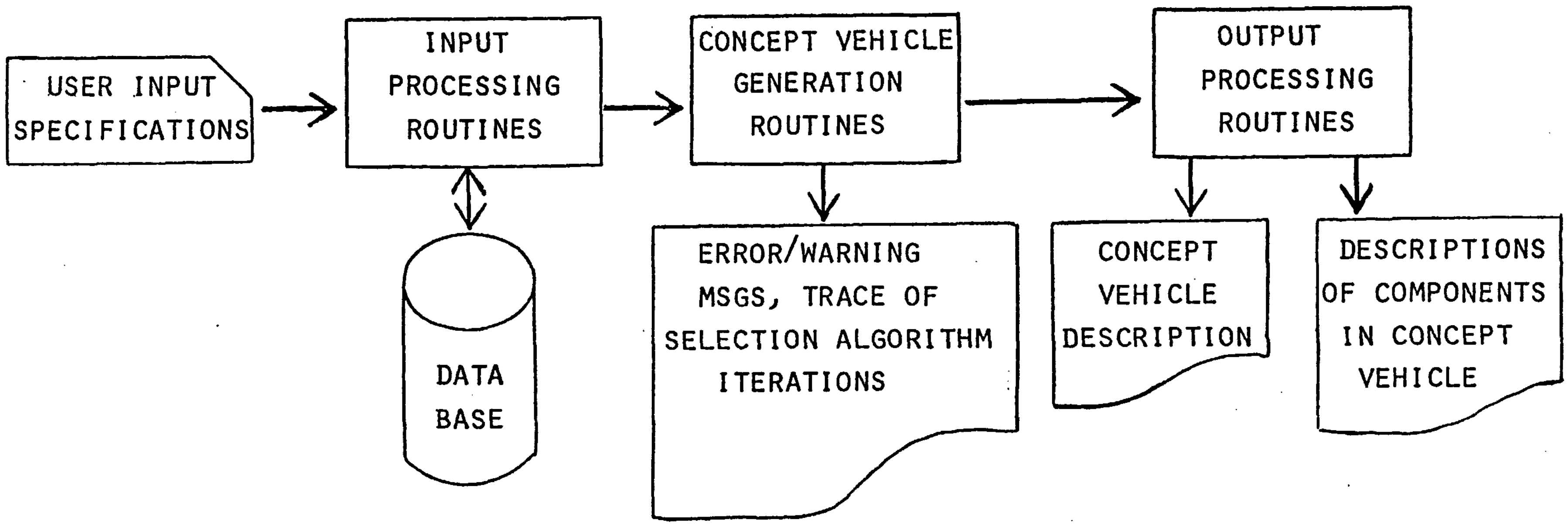


Exhibit 3 is the flow chart for the main program of the model. This flow chart indicates the modular nature of the program structure.

2.2 User Input Specifications

As indicated in exhibit 2, the model user must supply as input to the model a small set of specifications for the concept vehicle. These may be in the form of:

- specific components to be included on the vehicle;
- constraints on the engineering parameters of components;
- constraints on total system engineering or performance parameters; or
- combinations of the above.

User supplied input also includes a designation of the class of vehicle under consideration and an initial estimate of gross weight. A more detailed discussion of user inputs is found in chapter 3.0.

2.3 Data Base

The data base contains the following types of files:

- generic vehicle files;
- reference vehicle files;
- component files; and
- functional relationship files.

Data stored in each of these files are self identifying, i.e., associated with each data item is an input name or abbreviation which identifies the type of data.

EXHIBIT 3: MAIN PROGRAM FLOWCHART

FLOWCHART	COMMENTS
START	
CALL INIT	INIT initializes arrays in the internal data structure
CALL INFUNC	INFUNC reads and stores functional relationship data (see section 2.3.4)
CALL INPROT	INPROT reads, processes, and stores data from the Generic Vehicle File (see section 2.3.1)
CALL INALTC	INALTC reads, processes, and stores data from the Components File (see section 2.3.3)
CALL INSPEC	INSPEC reads, processes, and stores user specifications (see section 2.2)
CALL INVEHC	INVEHC reads, processes, and stores data from the Reference Vehicle File (see section 2.3.2)
CALL GENVEH	GENVEH generates a concept vehicle to meet the user specifications (see sections 2.5 and 2.6)
CALL OUTVEH	OUTVEH formats and outputs a description of the generated concept vehicle (see section 2.7)
STOP	

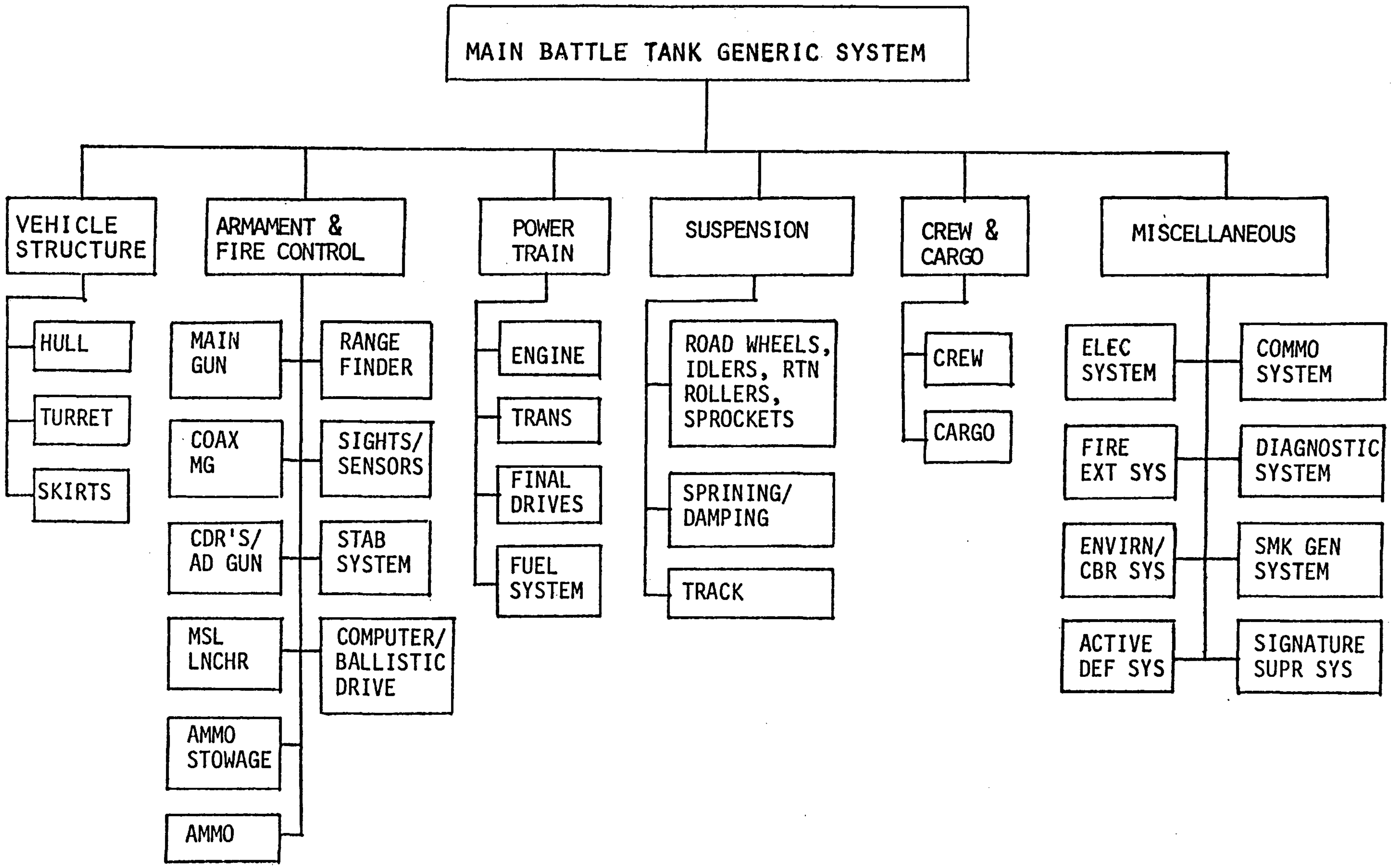
2.3.1 Generic Vehicle File

One generic vehicle file is needed for each class of vehicle. The file for a particular class of vehicle is used to:

- Specify the weapon system breakdown structure (i.e., sub-system and components within sub-system).
- Specify minimum and maximum number of each type component.
- Provide labels for output tables describing the generated concept vehicle.
- Provide default values for component selections and attribute values.
- Specify "input names" and abbreviations used to identify data in other files.
- Specify "symbolic subscripts" associated with components and attributes for use in storing and retrieving data in the internal data structure.
- Specify dimensions of input data arrays and output performance parameter arrays. It also provides labels for each dimension and each level within a dimension, e.g., dimension name: range; level labels: 1000m, 2000m, 3000m.

The weapon system breakdown structure specified by the generic vehicle file has three levels in the system hierarchy. These are the system, the sub-system, and the component levels. Exhibit 4 is an example of such a structure for "conventional" main battle tanks. Note that in this hierarchy such entities as the crew, the ammunition, basic load, and the fuel are treated as "components" in order to insure that all items relevant to the definition of a combat vehicle system are specified.

EXHIBIT 4: WEAPON SYSTEM BREAKDOWN STRUCTURE



The model considers a total of 31 different component types. For a given component type a concept vehicle might contain multiple selections of that type. For another component type a concept vehicle may contain none of that type. Component types are specified using a two-character code which is associated with that type by the generic vehicle file.

Attributes relevant to a description of an armored combat vehicle system can be divided into two classes:

- Those associated with systems as a whole, or
- Those associated with the system's components.

The second of these classes can be further subdivided into two classes:

- Those which are common to all components, e.g., weight, volume, etc., and
- Those specific to individual component types, e.g., main gun caliber, engine horsepower, etc.

Exhibit 5 displays the system parameters tabulated in the generic vehicle file for conventional tanks.

Exhibit 6a lists attributes common to most components of a conventional tank. Note that some attributes, such as cost, R&D time to complete development, etc., are tabulated, but are not used to compute system attributes such as total system acquisition costs, total system development time, etc.

Exhibit 6b lists attributes specific to individual component types.

EXHIBIT 5: ATTRIBUTES RELEVANT TO TANK AS A WHOLE
(system engineering and system performance parameters)

ATTRIBUTE	TABULATED AS FUNCTION OF
A. Structural	
weight	
volume	
height	
width	
length	
length/tread action	
track ground control length	
B. Firepower	
P_{hit} (std NATO Tgt)	range increments of 1000m, moving vs stationary firer
	moving vs stationary target, gun and ordinance type
$P_{kill/hit}$(Std Tgt)*	type of ammunition, range
C. Mobility	
gross hp/ton	
sprocket hp/ton	
average ground pressure	
max height of obstacle vehicle can cross	
max width of ditch vehicle can cross	

*e.g. T-62 tank.

EXHIBIT 5: ATTRIBUTES RELEVANT TO TANK AS A WHOLE
(system engineering and performance parameters)

(continued)

ATTRIBUTE

max depth of water vehicle can cross
without preparation

max depth of water vehicle can cross
with preparation

max speed on hard level road

max speed, 30% slope

range on good roads (fuel under armor)

range on good roads (total fuel)

time to accelerate from 0-20 mph

max slope that can climb

turning

rate (pivot turn) (rpm)

radius

1st gear fwd
4th gear fwd
1st gear rvs
2nd gear rvs

braking distance from 30 mph

max slope that can park on

average speed over terrain roughness class 1

average speed over terrain roughness class 2

EXHIBIT 5: ATTRIBUTES RELEVANT TO TANK AS A WHOLE
(system engineering and performance parameters)

(concluded)

ATTRIBUTE	TABULATED AS FUNCTION OF
D. Protection	
$P_{survival/hit}$	type of ammunition range
E. Ram/D	
maturity index,	
complexity index,	
estimated reliability (MMBF)	
estimated maintenance man-hours per operational hours	
F. COST*	
acquisition	
operating	

*Although costs are included in data, the model does not attempt to estimate costs of conceptual systems.

EXHIBIT 6a: ATTRIBUTES COMMON TO MOST COMPONENTS

- Weight
- Volume
- Cost
  - acquisition
  - operating
- For a new system:
  - R&D cost
  - R&D time
- RAM/D measures
  - maturity index (1. concept no design; 2. designed, no prototype; 3. development prototype available; 4. new production system; 5. mature system)
  - complexity index (1. straight-forward; 2. moderately complex; 3. complex)
  - empirical reliability measure (MMBF)
  - ratio of operational man-hrs/maintenance man hours
  - number of items fielded
- Identification of component
  - nationality
  - manufacturer
  - model
  - year first produced (or projected to be produced)
- Location of component in tank (e.g., 1. inside hull; 2. inside turret; 3. outside hull and turret)
- Evaluation measures:
  - firepower
  - mobility
  - protection
  - cost
  - RAM/D

EXHIBIT 6b: ATTRIBUTES SPECIFIC TO INDIVIDUAL COMPONENT TYPES

A. STRUCTURE/BALLISTIC PROTECTION SUBSYSTEM

A.1 HULL STRUCTURE

HEIGHT
LENGTH
WIDTH
ARMOR TYPE
THICKNESS SIDE ARMOR
THICKNESS REAR ARMOR
THICKNESS FRONT UPPER
THICKNESS FRONT LOWER
THICKNESS FRONT DECK
THICKNESS REAR DECK
THICKNESS BOTTOM
UPPER GLACIS OBLIQUITY
LOWER GLACIS OBLIQUITY
LOWER BACK ARMOR OBLIQUITY
LENGTH DRIVERS COMPARTMENT
CLEARANCE, DRIVERS SEAT - TURRET RING
TURRET RING DIAMETER
CLEARANCE, TURRET RING - ENGINE
DISTANCE, FLOOR - TURRET PLATFORM
DISTANCE, TURRET PFRM - CEILING
HEIGHT DRIVER COMPARTMENT

A.2 TURRET STRUCTURE

HEIGHT
LENGTH
WIDTH
ARMOR TYPE
MAIN GUN - SIDE DEST
CLEARANCE, PFRM - RING
FRONT DECK - MA AXIS
REAR DECK - MA AXIS
TURRET AXIS - FRT EDGE
TURRET AXIS - TRUNNION
THICKNESS FRONT ARMOR
THICKNESS SIDE ARMOR
THICKNESS BUSTLE BOTTOM ARMOR
THICKNESS BACK ARMOR
THICKNESS CEILING ARMOR

EXHIBIT 6b: ATTRIBUTES SPECIFIC TO INDIVIDUAL COMPONENT TYPES

(Continued)

A.3 ARMOR SKIRTS

ARMOR TYPE
HEIGHT
THICKNESS

B. ARMAMENT/FIRE CONTROL SUBSYSTEM

B.1 MAIN GUN

MUZZLE VELOCITY
TUBE LEN (CALIBERS)
CALIBER
ALLOWABLE AMMO TYPES
BORE TYPE
1. RIFLED
2. SMOOTH BORE
3. PARTLY RIFLED
LOADING TYPE
1. MANUAL
2. AUTOMATIC
TIME TO FIRE 1ST RD
TIME TO FIRE SUBS RDS
FIRE RATE, AIMED GUN
DISPERSION STD DEV
MAX ELEVATION
MAX DEPRESSION
MIN VEHICLE WEIGHT
HALF WIDTH OF BREECH
TRUNNION - REAR BREECH
LENGTH LONGEST ROUND
OUTSIDE DIAM OF GUN

B.2 COAXIAL MACHINE GUN

MUZZLE VELOCITY
TUBE LEN (CALIBERS)
CALIBER
ALLOWABLE AMMO TYPES
BORE TYPE
LOADING TYPE
TIME TO FIRE 1ST RD
TIME TO FIRE SUBS RDS
FIRE RATE, AIMED GUN
COVER FOR FIRER
HORIZ MOVE CONSTRAINTS
MAX ELEVATION
MAX DEPRESSION
MIN VEHICLE WEIGHT

EXHIBIT 6b: ATTRIBUTES SPECIFIC TO INDIVIDUAL COMPONENT TYPES

(Continued)

B.3 LOADER'S GUN

[SAME AS FOR COAXIAL MACHINE GUN]

B.4 COMMANDER'S/AIR DEFENSE GUN

[SAME AS FOR COAXIAL MACHINE GUN]

B.5 RANGING SYSTEM

TYPE (1-STEROSCOPIC; 2-LASER; 3-SUPERPOSITION;
4-MACHINE GUN)
RANGING ACCURACY AT 2000M
CONTRIBUTION TO MAIN GUN ERROR (STANDARD DEVIATION)

B.6 SENSING/SIGHTING

TYPE (1-OPTICAL; 2-THERMAL; 3-RADAR)
PERSON(S) APPLICABLE TO (1-COMMANDER; 2-GUNNER;
3-LOADER; 4-DRIVER; 5-2 OR 3 PERSONS;
6-ALL PERSONS)

ANGLE OF VIEW
MAGNIFICATION
PERFORMANCE: RANGE AT WHICH (1) DETECT, (2) RECOGNIZE
(3) IDENTIFY; DURING
(A) DAY OR (B) NIGHT

B.7 STABILIZATION SYSTEM

TYPE
PERFORMANCE CATEGORY

B.8 GUN POSITIONING AND CONTROL SYSTEM

TYPE
PERFORMANCE CATEGORY
CONTRIBUTION TO MAIN GUN ERROR (STD DER)

B.9 AMMUNITION

TYPE ROUND
NUMBER OF ROUNDS CARRIED
CALIBER
GUIDANCE (1-NONE; 2-PASSIVE HOMING ON REFLECTED LASER
3-HOMING ON TARGET SIGNATURE)

EXHIBIT 6b: ATTRIBUTES SPECIFIC TO INDIVIDUAL COMPONENT TYPES

(Continued)

B.10 AMMUNITION STORAGE

TOTAL CAPACITY, MAIN GUN ROUNDER

C. POWER TRAIN

C.1 ENGINE

TYPE (1-DIESEL; 2-TURBINE; 3-SPARK, RECIPROCATING 4-ROTARY)
HORSEPOWER
COOLING REQUIREMENTS
FUEL REQTS, NORMAL
FUEL REQTS, EMERGENCY
TRANSMISSION REQTS
STARTING TIME
MIN STARTING TEMP
MIN START TEMP, AIDS
LENGTH
WIDTH
HEIGHT
CLEARANCE TO REAR DECK
CLEARANCE TO SIDEWALL

C.2 TRANSMISSION

TYPE (1-MANUAL; 2-HYDROKINETIC; 3-HYDROMECHANICAL)
EFFICIENCY (HP TRANSMITTED)
NUMBER FORWARD GEARS
NUMBER REVERSE GEARS
LENGTH
WIDTH
CLEARNACE TO REAR WALL
ENGINE COMPATIBILITY CODE

C.3 FINAL DRIVERS

TYPE
EFFICIENCY (% HP TRANSMITTED)

C.4 FUEL

QUANTITY (GALLONS)
TYPE

EXHIBIT 6b: ATTRIBUTES SPECIFIC TO INDIVIDUAL COMPONENT TYPES

(Continued)

C.5 FUEL TANKS

CAPACITY (GALLONS)

D. SUSPENSION

D.1 ROADWHEELS, DRIVE SPROKCETS, IDLER AND RETURN WHEELS

NUMBER OF ROAD WHEELS PER SIDE
NUMBER OF IDLERS AND RETURN ROLLERS PER SIDE
DIAMETER OF ROAD WHEELS

D.2 WHEEL TRAVEL AND DAMPING MECHANISMS

MAX WHEEL TRAVEL
TYPE OF DAMPING
TYPE OF SPRINGING
PERFORMANCE CLASS OF SYSTEM
DYNAMIC SUSPENSION ADJUSTMENT CAPABILITIES

D.3 TRACK

TYPE (1-SINGLE PIN; 2-DOUBLE PIN; 3-BAND)
MATERIAL
LENGTH (ALONG GROUND)
LENGTH (FROM SPROCKET TO IDLER)
WIDTH
HEIGHT (GROUND TO TOP OF RETURN ROLLERS)
DISTANCE BETWEEN TRACK CENTERLINES
NUMBER TRACK SHOES/TRACK

E. CREW AND CARGO

E.1 CREW NUMBER

E.2 CARGO

F. MISCELLANEOUS

F.1 ELECTRICAL SYSTEM

TYPE (1-STANDARD; 2-ATEPS)

F.2 COMMUNICATIONS

TYPE OF SYSTEM
RANGE OF BROADCAST

EXHIBIT 6b: ATTRIBUTES SPECIFIC TO INDIVIDUAL COMPONENT TYPES

(Concluded)

F.3 FIRE EXTINGUISHER

TYPE OF SYSTEM FOR CREW
TYPE OF SYSTEM FOR ENGINE

F.4 ENVIRONMENTAL CONDITION CBR

TYPE OF SYSTEM

F.6 DIAGNOSTIC SYSTEM

TYPE

F.7 SIGNATURE SUPPRESSION

TYPE: (1-INFRARED; 2-ELECTROMAGNETIC; 3-CAMOFLAGE; 4-NOISE; 5-RADAR; 6-EXHAUST SMOKE)

F.8 SMOKE GENERATION SYSTEM

TYPE: (1-SMOKE GRENADE SYSTEM; 2-SMOKE EXHAUST SYSTEM)

F.9 AUTOMATIC DEFENSE SYSTEM

TYPE

2.3.2 Reference Vehicle Files

The reference vehicle files may contain descriptions of:[1]

- currently fielded systems,
- developmental systems, or
- conceptual systems.

The data stored for each vehicle system in the file include engineering and performance parameters for the total system and the engineering parameters associated with each major component incorporated in the systems. The set of attributes listed in exhibits 4,5 and 6 in section 2.2.1 above is also used in describing vehicles and their components in the reference vehicle file.

2.3.3 Components File

The components file contains descriptions of components in terms of their engineering parameters. This file may contain descriptions of:

- existing components which have been produced in series.
- prototype components for which required production tooling does not exist,
- developmental components, based on current or emerging state-of-the-art, but for which no prototype exists, or
- conceptual components, based on projected state-of-the-art improvements.

The use of conceptual and developmental components allows investigation of vehicle components incorporating projected technology

advances, e.g., an adiabatic engine. The set of attributes listed in exhibits 5 and 6 in section 2.2.1 above are also used to describe components in the components file.

2.3.4 Functional Relationships File

The Functional Relationships File stores "look-up table" data used by the model to estimate performance. The input processing routine for this file allows suppression of some dimensions of the table. For example, if performance parameter Y is normally tabled as a function of engineering parameter I,J,K and L, it is possible to use any subset y at least one of these as table dimensions. For some tables it is possible to use variable increments for table values. For example, ride-limited speed rough terrain might be tabled for road wheel travel values of 6", 8", 13" and 16". (See section 2.6.3 for additional discussion of functional relation look-up tables.)

2.4 Input Routines and Internal Data Structure

The initialization and input routines[1] initialize the internal data arrays and read the user input specifications and the files in the data base. These routines also transform the user specifications and the descriptions of vehicles and components in the data base into an internal data structure for use by the solution routines. For example, user specifications are converted into an internal constraint data structure which guides the selection of components by the solution routines.

---

[1]This set of routines includes INIT, INFUNC, INPROT, INALTC, INSPEC, and INVEHC shown in the flow chart of the main program in exhibit 3 (see section 2.1).

Descriptions of components in the data base are transformed into an internal available component data structure. The solution routine generates an internal description of the concept vehicle, which is transformed by the output routines into a variety of tables describing the generated concept vehicle and its components.

An internal data structure was developed for storing the following types of information:

- user specifications in the form of a constraint data structure;
- the weapon system breakdown structure, attribute labels and other information read from the generic vehicle file;
- attributes of vehicles read from the reference vehicle file;
- attributes of components read from the components file;
- the description of the vehicle generated by the solution routine;
- "look-up table" functional relationships.

The design for storing the above information is a "Plex" list structure. Elements of this structure are:

- variables (scalars);
- records (vectors of scalars); and
- lists.

The value of any variable, record field, or list element may be a data item or a pointer to a list of records, a particular record, or a field in a record.

In this structure a vehicle description has a particular form. The plex structure for description of a particular vehicle is pointed to by the variable representing the name of the vehicle. This structure

consists of a main vehicle record (a 72-element vector) which points to components of each type and also stores attributes for the vehicle as a whole. Those fields of the vehicle record associated with each type of component may have one of the following values:

- null (indicating that a component of that type has not been specified),
- a pointer to a component record of the appropriate type, or
- a pointer to a list of specifications for the appropriate component type (for the "specification vehicle" record).

Those fields of the vehicle record associated with system attributes may contain:

- a scalar data item indicating the value of the attribute,
- a null value, indicating that the value of the attribute is unknown,
- a pointer to an array of values for attributes which are multi-dimensional, e.g., P_{hit} as a function of range, round type, and target motion, or
- a pointer to a constraint record (for the specification vehicle record).

Component records will have fields for both the common attributes and those specific to the component type.

If the attributes are array valued, e.g., a table indexed on range, etc., the associated field in the component record will be a pointer to an array of values for that attribute.

Exhibit 7 illustrates the plex structure for the description of a conceptual vehicle.

Unique names consisting of eight characters or less have been assigned to:

- each component type,
- each vehicle system attribute,
- each of the attributes common to most components, and
- each attribute specific to individual components.

In addition, there is associated with each component and attribute a "symbolic subscript" which is used as a pointer to the field in records of various types associated with that type of component or attribute. There is also a unique two-character component code associated with each component type. Exhibit 8 lists the components, the input names, the symbolic subscripts (both the FORTRAN name and the value assigned to each), and the component code. These names and codes are specified in the generic vehicle file and are used in the user input specification, reference vehicle files, and components files to identify component types. Exhibit 9 lists the input names and symbolic subscripts for attributes applicable to the system as a whole. Exhibit 10 lists the input names and symbolic subscripts for common attributes of components, and exhibit 11 lists the same for attributes specific to each component. The symbolic subscripts listed in exhibits 9, 10, and 11 are used as the

EXHIBIT 7: PLEX STRUCTURE

DESCRIPTION OF CONCEPTUAL VEHICLE

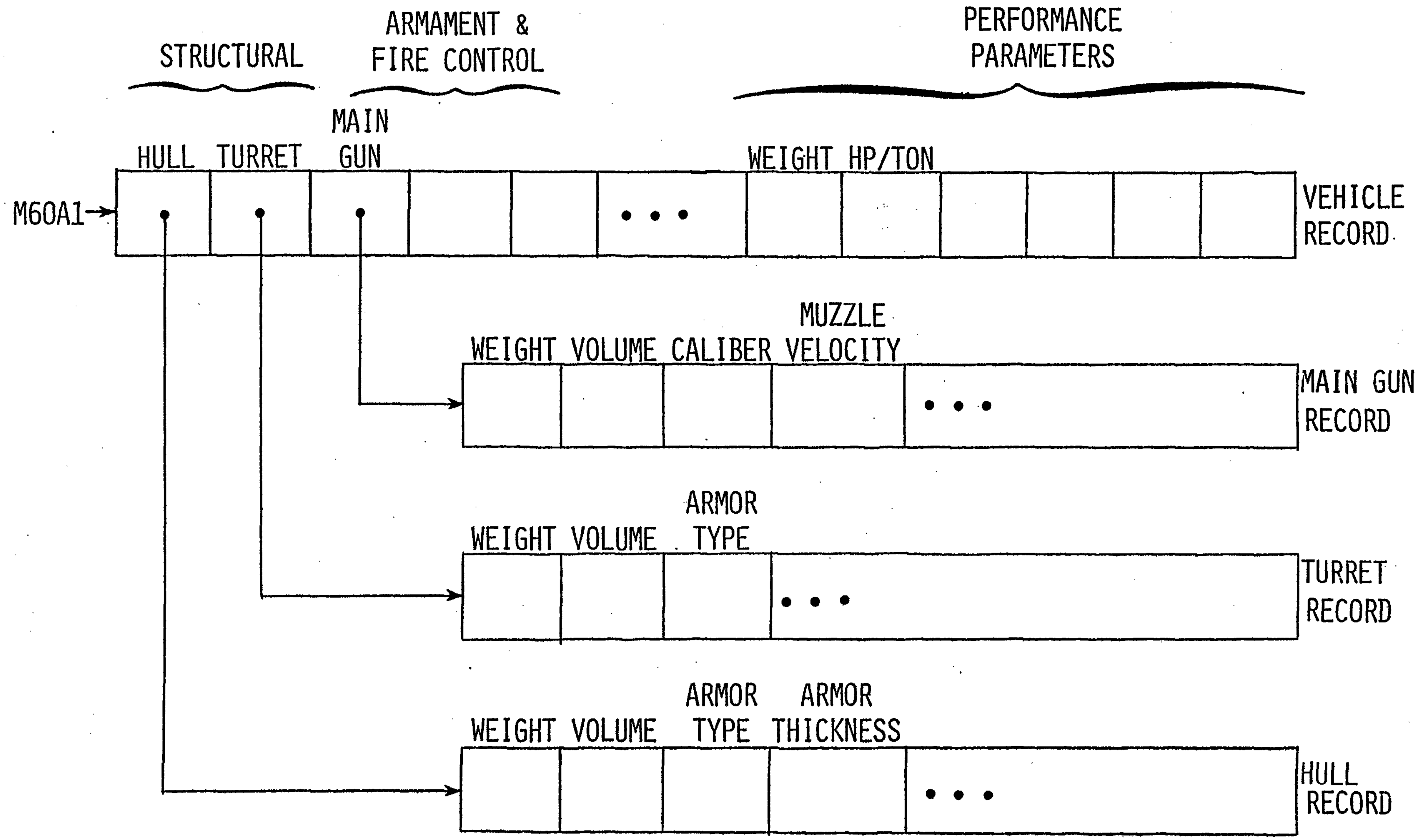


EXHIBIT 8: NAMES AND CODES ASSOCIATED WITH EACH COMPONENT TYPE

Component	Input Name	Symbolic Subscript FORTRAN Name	Value	Component Code
A. Structure/Ballistic Protection				
Hull	HULL	JHULL	1	HL
Turret	TURRET	JTURET	2	TU
Armor Skirts	SKIRTS	JSKIRT	19	SK
B. Armament/Fire Control				
Main Gun & Mount	MAIN GUN	JMAING	3	GU
Coax Mach Gun	MACH GUN	JMACHG	4	MG
Loader's Gun	MISSILE L*	JMISL	5	ML
Cor's/Ad Gun	AD GUN	JADGUN	6	AD
Ranging System Sensing/ Sighting System	SENSORS	JSENSR	8	SN
Stabilization System	STAB SYS	JSTBSY	9	ST
Gun Control System	GUN CONT	JCTLSY	10	GC
Ammunition	AMMO	JAMMO	11	AM
Ammo Storage	AMMO STO	JAMMOC	12	AS
C. Power Train				
Engine	ENGINE	JENGIN	13	EN
Transmission	TRANSMIS	JTRANS	14	TR
Final Drive	FIN DRIV	JFINDR	15	FD
Fuel	FUEL	JFUEL	20	FU
Fuel Containers	FUEL TNK	JFUELC	21	FT
D. Suspension				
Road Wheels, Idlers, Sprokets, & Rtn Rollers	ROAD WH	JROADW	16	RW
Springing & Damping	SPR DAMP	JSUSP	17	SD
Track	TRACK	JTRACK	18	TK
E. Crew and Cargo				
Crew	CREW	JCREW	22	CR
Cargo	CARGO	JCARGO	23	CG
F. Miscellaneous				
Electrical System	ELEC SYS	JELEC	24	EL
Communications	COMMO	JCOMMO	25	CM
Fire Exting System	FIRE EXT	JFIREX	26	FE
Environ/CBR System	ENVR SYS	JENVR	27	EC
Diagnostic System	DIAG SYS	JDIAGN	28	DS
Signature Sup System	SIGN SUP	JSIGSP	29	SS
Smoke Gen System	SMOK GEN	JSMOKE	30	SG
Auto Def System	EW SYS	JEWSYS	31	EW

*This component type was originally a missile launcher. It can be used for any auxiliary weapon.

EXHIBIT 9: INPUT NAMES AND SYMBOLIC SUBSCRIPTS FOR SYSTEM ATTRIBUTES

Attribute	Input Name	Symbolic Subscript FORTRAN Name	Value
Weight	WEIGHT	JVWT	33
Volume	VOLUME	JVVOL	34
Height	HEIGHT	JVHT	35
Width	WIDTH	JVWID	36
Length	LENGTH	JVLEN	37
Length/Tread	L/T	JLT	67
Track Grd Contact Ln	TRACK GC	JYGC	68
P Hit, Stat Fire	P HIT ST	JPHITS	38
P Hit, Move Fire	P HIT MY	JPHITM	39
P (Kill/Hit)	P KILL	JPK	40
Gross HP/Ton	HP/TON	JGHPTN	41
Sproket HP/Ton	S HP/TON	JSHPTN	42
Av Grd Pressure	GRS PRES	JGPRES	43
Max Height Obstacle	HT OBST	JOHT	44
Max Width Ditch	WD DITCH	JDWID	45
Max Depth Water	DP WATER	JWDEPN	46
Max Dep Water, Prep	DP PREPN	JWDEPP	47
Max Road Speed	MX SPEED	JMXSPD	48
Max Speed, 30 Deg	MX 30SPD	J30SPD	49
Range (Prot Fuel)	RANGE A	JRANGA	50
Range	RANGE	JRANGE	51
Acceleration, 0-20	ACCELER	JACCEL	52
Max Slope Climb	MX SLOPE	JSLOPE	53
Turn Rate (Pivot)	TRN RATE	JTRATE	54
Turn Radius	TRN RAD	JTRAD	55
Braking Dist, 30 MPH	BRK DIST	JBRAKE	56
Max Slope, Park	PARK SLP	JPSLOP	57
Av Speed, Terrain 1	AV SPD1	JSPD1	58
Av Speed, Terrain 2	AV SPD2	JSPD2	59
Wt/Lineal Ft	TON/FT	JTONFT	69
P(Penetration/Hit)	PPENETR	JPENTR	60
Maturity Index	MATURITY	JVMATR	61
Complexity Index	COMPLEX	JVCMPX	62
Reliability Meas	JMBFF	JVMMBF	63
Maint Hrs/Op Hrs	NONOP/OP	JVOPHR	64
Acq Cost	ACQ COST	JVACOS	65
Operating Cost	O&S COST	JVOCOS	66

EXHIBIT 10: INPUT NAMES AND SYMBOLIC SUBSCRIPTS FOR COMMON ATTRIBUTES OF COMPONENTS

Attribute	Input Name	Symbolic Subscript FORTRAN Name	Value
Weight	WEIGHT	JWT	2
Volume	VOLUME	JVOL	3
Acq Cost	ACQ COST	JACOST	4
Operating Cost	O&S COST	JOCOST	5
R&D Cost	R&D COST	JRCOST	6
R&D Time	R&D TIME	JRTIME	7
Maturity Index	MATURITY	JMATUR	8
Complexity Index	COMPLEX	JCMPLX	9
Empirical Reliability	MMBF	JRELIB	10
Non-Op/Op Man-Hrs	NONOP/OP	JDWNUP	11
# Items Fielded	#FIELDED	JNUM	12
Nationality	NATION	JNAT	13
Manufacturer	MANUFACR	JMANUF	14
Model	MODEL	JMODEL	15
Year First Produced	YEAR	JYEAR	16
Location of Component	LOCATION	JLOC	17
Firepower Value	WT FPWR	JEFPWR	18
Mobility Value	WT MOBIL	JEMOB	19
Protection Value	WT PROT	JEPROT	20
Ram/D Value	WT RAMD	JERAMD	21
Cost Value	WT COST	JECOST	22

EXHIBIT 11: INPUT NAMES AND SYMBOLIC SUBSCRIPTS FOR ATTRIBUTES SPECIFIC TO EACH COMPONENT TYPE

Component Type/Attribute	Input Name	Symbolic Subscript FORTRAN Name	Symbolic Subscript Value
Hull			
Height	HEIGHT	JZH	25
Length	LENGTH	JYH	26
Width	WIDTH	JXH	27
Armor Type	ARMOR TP	JARMTP	28
Thickness Side Armor	X3	JX3	29
Thickness Rear Armor	Y9	JY9	30
Thickness Front Upper	THFU	JTHFU	31
Thickness Front Lower	THFL	JTHFL	32
Thickness Front Deck	Z4	JZ4	33
Thickness Rear Deck	Z12	JZ12	34
Thickness Bottom	Z2	JZ2	35
Upper Glacis Obliquity	GAMMAU	JGAMU	36
Lower Glacis Obliquity	GAMMAD	JGAMD	37
Lower Back Obliquity	DELTAD	JDELD	38
Length Drivers Compart	Y2	JY2	39
Clearance, Drv Seat-Turret Ring	Y3	JY3	40
Turret Ring Diameter	Y4	JY4	41
Clearance, Turret Ring - Engine	Y5	JY5	42
Distance, Floor-Turret Platform	Z8	JZ8	43
Distance, Turret PFRM - Ceiling	Z9	JZ9	44
Height Driver Compartment	Z3	JZ3	45
Turret			
Height	HEIGHT	JBI	25
Length	LENGTH	JAI	26
Width	WIDTH	JXTP	27
Armor Type	ARMOR TP	JARMTP	28
Main Gun - Side Dest	X2	JX2	30
Clearance, Pfrm - Ring	K1	JK1	31
Front Deck - Ma Axis	Z5	JZ5	32
Rear Deck - Ma Axis	Z13	JZ13	33
Turret Axis - Frt Edge	Y22	JY22	34
Turret Axis - Trunnion	Y23	JY23	35
Thickness Front Armor	TTF	JTTF	36
Thickness Side Armor	TTS	JTTS	37
Thickness Bottom Armor	TTU	JTTU	38
Thickness Back Armor	TTB	JTTB	39
Thickness Ceiling Armor	Z7	JZ7	40

EXHIBIT 11: INPUT NAMES AND SYMBOLIC SUBSCRIPTS FOR ATTRIBUTES SPECIFIC TO EACH COMPONENT TYPE

(Continued)

Component Type/Attribute	Input Name	Symbolic Subscript FORTRAN Name	Value
Skirts			
Armor Type	ARM TYPE	JTYPE	25
Height	HEIGHT	JSKHT	26
Thickness	THICKNESS	JSKTHK	27
Main Gun			
Muzzle Velocity	MUZZLE V	JMUZLE	25
Tube Len (Calibers)	TUBE LEN	JTBLEN	26
Caliber	CALIBER	JCALIB	27
Allowable Ammo Types	AMMO TYP	JAMOTP	28
Bore Type	BORE TYP	JBORE	29
Loading Type	LOAD TYP	JLOAD	30
Time to Fire 1st Rd	T FIRE 1	JTFIR1	31
Time to Fire Subs Rds	T FIRE S	JTFIRS	32
Fire Rate, Aimed Gun	FIRE RAT	JFRATE	33
Dispersion Std Dev	SIGMA	JSIGMA	34
Max Elevation	ELEVN	JELEVN	36
Max Depression	DEPRESN	JDPRES	37
Min Vehicle Weight	MIN V WT	JMINWT	38
Half Width of Breech	X1	JX1	39
Trunnion - Rear Breech	Y20	JY20	40
Length Longest Round	Y21	JY21	41
Outside Diameter of Gun	MGODIAM	JODIAM	42
Coaxial Machine Gun			
Muzzle Velocity	MUZZLE V	JMUZLE	25
Tube Len (Calibers)	TUBE LEN	JTBLEN	26
Caliber	CALIBER	JCALIB	27
Allowable Ammo Types	AMMO TYP	JAMOTP	28
Bore Type	BORE TYP	JBORE	29
Loading Type	LOAD TYP	JLOAD	30
Time to Fire 1st Rd	T FIRE 1	JTFIR1	31
Time to Fire Subs Rds	T FIRE S	JTFIRS	32
Fire Rate, Aimed Gun	FIRE RAT	JFRATE	33
Cover For Firer	SIGMA	JSIGMA	34

EXHIBIT 11: INPUT NAMES AND SYMBOLIC SUBSCRIPTS FOR ATTRIBUTES SPECIFIC TO EACH COMPONENT TYPE

(Continued)

Component Type/Attribute	Input Name	Symbolic Subscripts FORTRAN Name	Value
Coaxial Machine Gun (cont.)			
Horizontal Move Constraints	HORIZ MV	JHMOVE	35
Max Elevation	ELEVN	JELEVN	36
Max Depression	DEPRESN	JDPRES	37
Min Vehicle Weight	MIN V WT	JMINWT	38
Loader's Gun			
[Same as for coaxial machine gun.]			
Commander's/AD Gun			
[Same as for coaxial machine gun.]			
Ranging System			
Type	TYPE	JTYPE	25
Ranging Accuracy	RNG ACC	JACCUR	26
Std Deviation	SIGMA	JSIGMA	27
Sensing/Sighting System			
Type	TYPE	JTYPE	25
Persons Applicable To	PERSON	JPERSN	26
Angle of View	ANG VIEW	JANGLE	27
Magnification	MAGNIFIC	JMAG	28
Effective Range	DET RNG	JDTRNG	29
Stabilization System			
Type	TYPE	JTYPE	25
Performance Category	PERFORM	JPERF	26
Gun Position & Control System			
Type	TYPE	JTYPE	26
Performance Category	PERFORM	JPERF	27
Dispersion Std Dev	SIGMA	JSIGMA	28

EXHIBIT 11: INPUT NAMES AND SYMBOLIC SUBSCRIPTS FOR ATTRIBUTES SPECIFIC TO EACH COMPONENT TYPE

(Continued)

Component Type/Attribute	Input Name	Symbolic Subscripts FORTRAN Name	Value
Ammunition			
Type	TYPE	JTYPE	25
Nr Rds Carried	NO RDS	JNRDS	26
Caliber	CALIBER	JCALIB	27
Guidance System	GUIDANCE	JGUIDE	28
Ammo Storage			
No specific attributes.			
Engine			
Type	TYPE	JTYPE	25
Horsepower	HP	JHP	26
Cooling Requirements	COOL RQT	JCOOLR	27
Fuel Requirements, Normal	FUEL RQT	JFUELN	28
Fuel Requirements, Emergency	FUEL EMR	JFUELE	29
Transmission Requirements	TRAN RQT	JTRNRQ	30
Starting Time	ST TIME	JSTIME	31
Min Starting Temperature	ST TEMP	JSTEMP	32
Min Starting Temperature, Aids	ST TEMP2	JSTEM2	33
Length	Y6	JY6	34
Width	X5	JX5	35
Height	Z10	JZ10	36
Clearance to Rear Deck	Z11	JZ11	37
Clearance to Sidewall	X6	JX6	38
Transmission			
Type	TYPE	JTYPE	25
Efficiency (% HP Out)	EFFIC	JEFFIC	26
No Forward Gears	FWD GEAR	JNFWDG	27
No Reverse Gears	RVS GEAR	JNRVSG	28
Length	X7	JX7	29
Width	Y7	JY7	30
Clearance to Rear Wall	Y8	JY8	31
Engine Compatibility Key	TRAN KEY	JKEY	32

EXHIBIT 11: INPUT NAMES AND SYMBOLIC SUBSCRIPTS FOR ATTRIBUTES SPECIFIC TO EACH COMPONENT TYPE

(Continued)

Component Type/Attribute	Input Name	Symbolic Subscripts FORTRAN Name	Value
Final Drives			
Type	TYPE	JTYPE	25
Efficiency	EFFIC	JEFFIC	26
Length	X8	JX8	27
Fuel			
Type	TYPE	JTYPE	25
Quantity	QUANTITY	JFGAL	26
Fuel Tanks			
Capacity	CAPACITY	JFCAP	26
Road Wheels, Etc.			
No. Road Wheels/Side	# RD WHL	JNRDWH	25
No. Return Wheels	# RETURN	JNRETN	26
Diameter of Rd Wheels	WH DIAM	JD3	27
Drive Sproket Diam	D2	JD2	28
Front Idler Diameter	D1	JD1	29
Height of Sproket	Z15	JZ15	30
Height of Idler	Z14	JZ14	31
Ground Clearance	Z1	JZ1	32
Lead Angle of Track	BETAF	JBETAF	33
Trailing Angle Track	BETAR	JBETAR	34
Springing/Damping			
Max Wheel Travel	WH TRVL	JWHTRV	25
Performance Class	PERFORM	JPERF	26
Type of Damping	DAMPING	JDAMP	27
Type of Springing	SPRINGING	JSPRNG	28
Dyn Susp Adjustment	SUSP ADJ	JSADJ	27
Track			
Type	TYPE	JTYPE	25
Material	MATERIAL	JMATER	26
Width	WIDTH	JX4	27
Thickness	T	JT	28

EXHIBIT 11: INPUT NAMES AND SYMBOLIC SUBSCRIPTS FOR ATTRIBUTES SPECIFIC TO EACH COMPONENT TYPE

(Concluded)

Component Type/Attribute	Input Name	Symbolic Subscripts FORTRAN Name	Value
Crew			
Number	NUMBER	JNCREW	25
Cargo			
No specific attributes.			
Electrical System			
Type	TYPE	JTYPE	25
Communications			
Type	TYPE	JTYPE	25
Range	RANGE	JPERF	26
Fire Extinguisher			
Type System for Crew	FIREX C	JTYPE	25
Type System for Engine	FIREX E	JTYPEE	26
Environmental/CBR System			
Type System	TYPE	JTYPE	25
Diagnostic Systems			
Type	TYPE	JTYPE	25
Signature Suppression System			
Type	TYPE	JTYPE	25
Smoke Generation System			
Type	TYPE	JTYPE	25
Automatic Defense System			
Type	TYPE	JTYPE	25

names of record fields in the programming logic for referencing the internal data structure. For example, in internal records containing attributes associated with components the JWT field contains the weight of the component, the JVOL field etc. volume and so on.

Formats for user input specifications are described in chapter 3.0 in connection with instructions for operation of the model. The input routine INSPEC reads the user specifications and routine INVEHC transforms them into an internal representation of a "specification" vehicle. This specification vehicle provides a pattern against which the solution routine tests candidate solution concept vehicle. The specification vehicle record has each of its fields filled with one of the following types of values:

(1) a null value, indicating no selection or constraints are in effect,

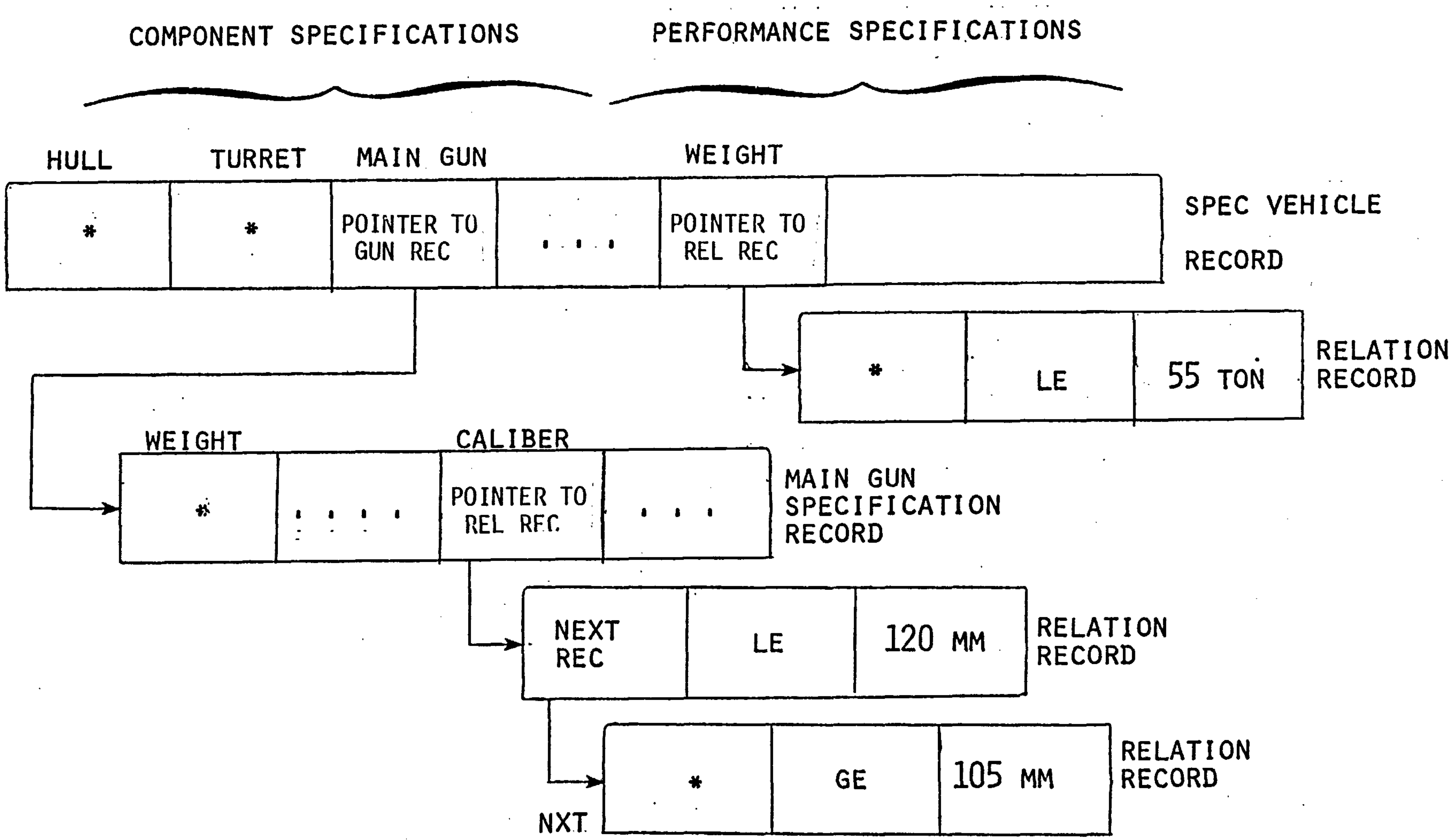
(2) a pointer to a component record or list of component records, indicating that a component as described by this component record is to be selected,

(3) a constant value, indicating that the corresponding field must assume this value (some fields may allow arrays of constants rather than a single scalar), or

(4) a pointer to a relation record or a list of relation records describing the constraints that apply to this field.

Any component record pointed to by the vehicle record allows a similar choice of value types for its fields as the vehicle record does, except that none of its fields will point to further component records. This structure is illustrated in exhibit 12. In this exhibit an asterisk indicates a null value. Note that there is a list of two relation (constraint) records

EXHIBIT 12: PLEX STRUCTURE FOR SPECIFICATIONS



associated with the main gun attribute caliber. In the example shown, they jointly specify:

$$105 \text{ mm} \leq \text{CALIBER} \leq 120 \text{ mm}.$$

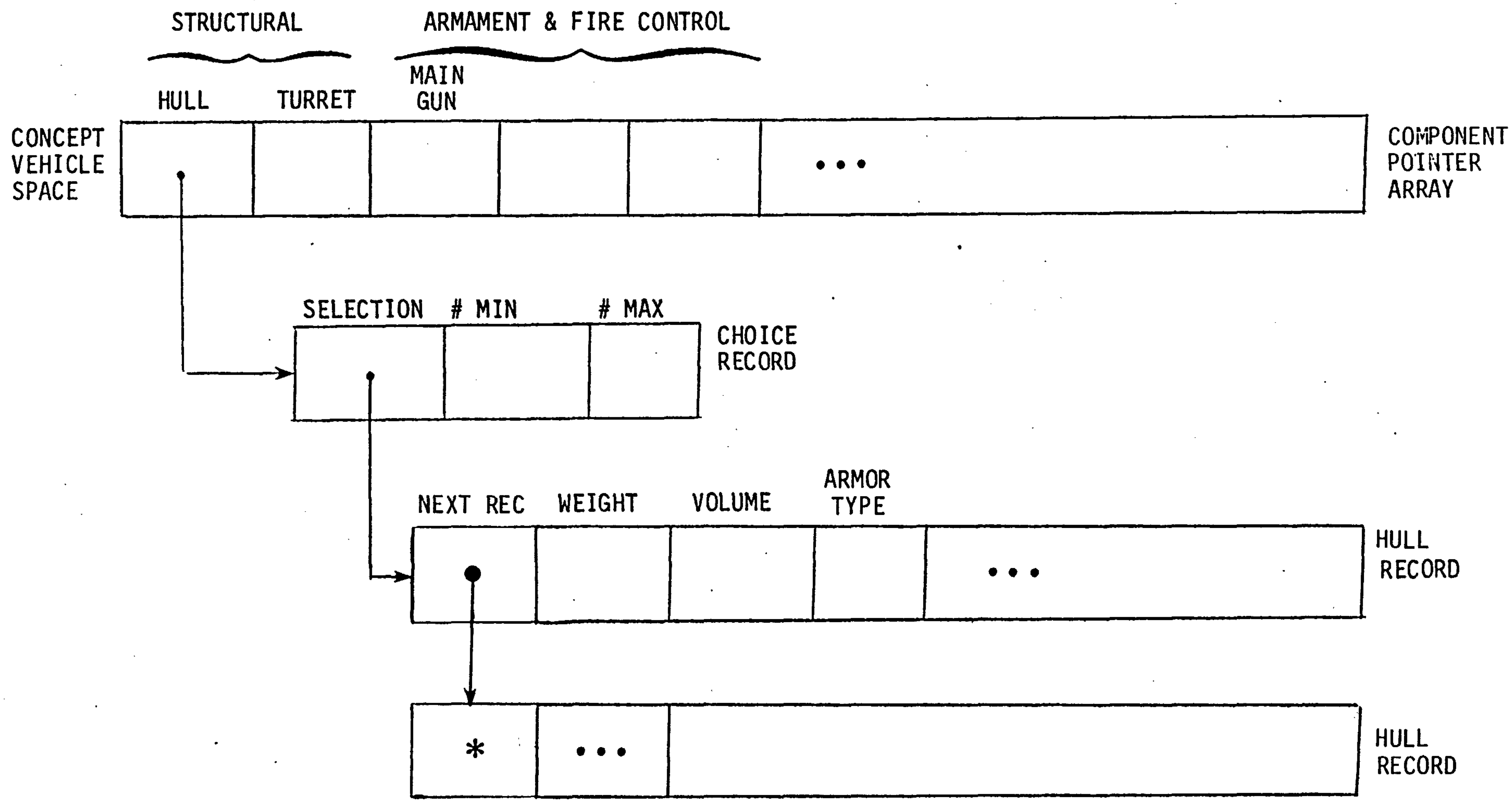
In describing the solution space of conceptual vehicle systems, the input routines use information read by subroutine INPROT to determine the types of components in a vehicle of the class under consideration and the minimum and maximum number of components of each type. INPROT reads this information from the Generic Vehicle file. To provide a selection of components for generating a concept vehicle subroutines INVEH and INALT read component descriptions from the Reference Vehicles and Components files, respectively. A portion of the data structure for the alternative components is shown in exhibit 13. Note that the exhibit shows a list of two alternative hulls available for selection.

The internal structure for representation of the concept vehicle generated by the solution routine is identical in form to that used for the internal representation of reference vehicles (see exhibit 7). This structure is built up component by component by the solution algorithm discussed in the next section.

2.5 *Solution Routines*

Subroutine GENVEH is the main routine which generates a concept vehicle to meet the user specifications. In addition to GENVEH the solution routines include function OKCOMP, which checks components against user specifications; function COMPAT, which checks component capability; and subroutine DIMENS, FPOWER, and MOBILE, which compute estimates of system engineering and performance parameters. Together

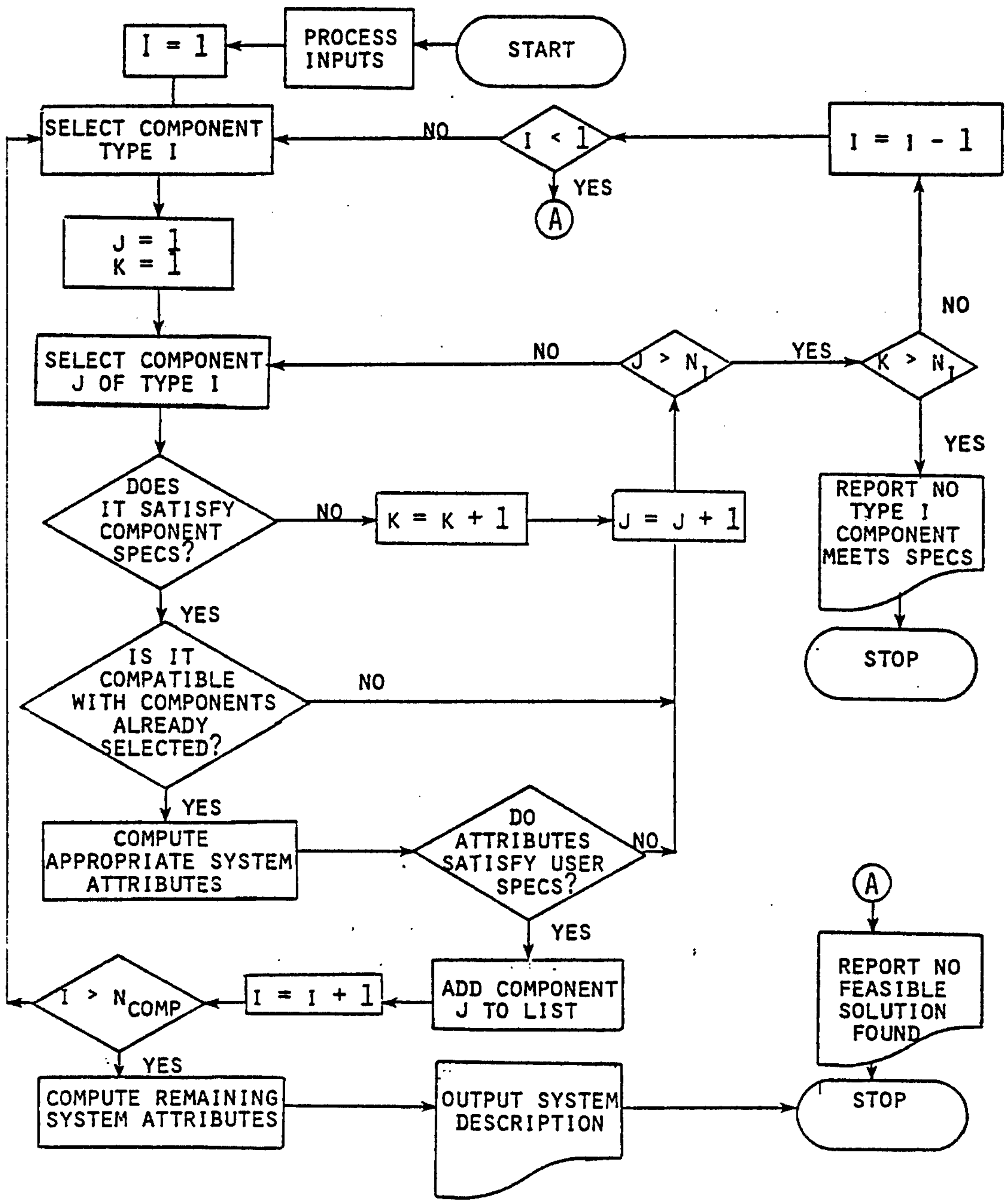
EXHIBIT 13: INTERNAL REPRESENTATION OF THE SET OF ALTERNATIVE COMPONENTS



these routines are the heart of the model. They use the description of the concept vehicle solution space and the user specifications to search over alternative combinations of components to find one which satisfies the constraints specified by the user. The solution algorithm works by essentially selecting one or more components of each allowable type as specified in the solution space and building up a concept vehicle description from these choices. Each component selected must be consistent with the user specifications and with the other components selected. Performance parameters which the program derives from the selected set of components must also satisfy the user specifications.

The method employed for deriving a solution concept vehicle description is a "backtrack" programming approach [Floyd, 1967]. A flow diagram of this algorithm is presented in exhibit 14. A brief description of the operation of the algorithm for solving a small well-structured puzzle, the "eight queens problem", may serve to give the reader a better understanding of its operation and to focus attention on its salient features. The goal of the eight queens problem is to find a way to put eight queens on a chessboard so that no queen is attacked by any other (although many solutions exist, finding one is not trivial). Since a legal move for a queen in chess is any number of squares in a horizontal, vertical, or diagonal direction, and since a chessboard consists of an 8x8 array of squares, it is immediately apparent that for any solution each row and column of the chessboard must be occupied by one and only one queen. It is not immediately obvious, however, how to arrange the eight queens so that this holds and also so that no queen attacks another along a diagonal. The backtrack programming method is a systematic search procedure which can be used to find such a solution. The search space can be organized

EXHIBIT 14: "BACKTRACKING" SOLUTION ALGORITHM



first by columns, and then within columns by rows. Each queen can be associated with a column. The object is to determine its appropriate row. One begins with the first queen, looking for the first row that it can validly occupy. Since there are no other queens yet on the board and hence no constraints on this queen, row 1 is the first possible valid choice and it is placed there in position (1,1). Whenever any queen is situated one continues with the next queen. Continuing with queen 2, the first valid row at which it will not attack any preceeding queens (queen 1) is row 3. It is placed here, at position (3,2). The algorithm continues in this fashion queen by queen. If when queen i is encountered there are no valid rows for it to occupy, this implies that the selections of positions for queens 1 through i-1 led to a dead-end. At this point one backs up to the previous queen positioned (i-1) and attempts a new positioning for this queen. If it is currently sitting on row j, then rows 1 to j have already been tried; consequently, finding a new valid row for this queen begins again with row j+1. Failing to find a new valid position for this queen, one backs up to column i-2. Continuing in this fashion the algorithm will end either (1) when all eight queens have been successfully positioned on the chessboard or (2) if the problem had no solution, the alternative rows for queen 1 would eventually become exhausted, indicating failure to find a solution.

The types of components of the concept vehicle are analogous to the queens of the 8-queen problem. Selection of a particular component of a given type is analogous to selection of an appropriate row for a given queen. Just as the queen must meet the constraint of not attacking any previous

queens already positioned on the board, the selected component must meet the constraints of being compatible with previously selected components and being compatible with the user specifications. A successful candidate concept vehicle is achieved when components of each type are selected. If no combination of components is compatible with each other and with the user's specifications then there is no feasible solution for those specifications, given the set of components in the solution space (i.e., those input from the data base).

Although there is a strong analogy between the 8-queens problem and our approach to concept vehicle definition, there are some important differences as well. First of all, all eight queens are identical to each other. Although there is a set of attributes common to all components (such as weight and volume), each component also has its own distinctive attributes (such as gross horsepower for an engine). Since the components of a vehicle differ from each other, selecting the order in which they are processed is important. The processing order has been designed: (1) to identify dead-end combinations as rapidly as possible and (2) properly account for the dependence of the possible choices for some components on previous selections made. For instance, the structure of the hull and turret enclose and protect most of the other components. The required structural dimensions are dependent on the space requirements of the components inside the structure. Thus, hull and turret structure are handled after the components inside the tank are treated.

The above example illustrates another important difference between vehicle concept definition and the 8-queens problem. In the 8-queens problem all of the relevant attributes of a queen are initially well-defined. In the vehicle concept definition problem, some components have "open" parameters whose values must be computed. Thus, certain dimensions of the hull and turret structures are calculated after most of the components located inside the tank structure have been selected. The weight of the structure is also an open parameter. It is calculated from the surface area and thickness of various parts of the structure and type of the armor.

Another difference between the 8-queens problem and the concept vehicle definition problem is that in the former, the number of queens is fixed whereas in the latter the number of components can vary. The definition of the solution space specifies a minimum and a maximum number of components of each type to be selected (determined from the description of the generic vehicle as read from the data base). The concept vehicle solution space description might allow, for instance, 0 or 1 air defense guns, one or two coaxial machine guns, etc. The user can constrain the concept vehicle solution space definition even further by specifying how many components of a given type he wishes to have for the concept vehicle being defined.

A fourth difference between the eight queens problem and the concept vehicle definition problem is that in the latter there are additional derived

parameters that must be calculated. Some parameters, such as the speed over slope of specified grade, require most of the components to be selected before they can be calculated. Others, such as the probability of hit by the main gun against a standard target, require all components affecting main gun accuracy to be selected before being calculated. Parameters such as vehicle weight or internal volume are kept track of as running totals. These are updated as components are added to the vehicle or as backtracking occurs. Derived parameters are calculated at the earliest possible time so that user performance constraints can be tested for and dead-end paths aborted.

The backtracking logic requires that the selection of a component of any type depend only on the choices made previously for other types of components, not on the choices yet to be made. Preserving this property was complicated by the fact that the relationships in the vehicle definition problem are much more intertwined. The size and horsepower needed for a tank engine depends on the tank's weight. The tank's weight depends to a large extent on the amount of armor the tank has. The amount of armor a tank has depends on the volume of items enclosed by the armor, which in turn, depends partly on the size of the engine. The approach used to solve this problem was to require the user to provide an initial estimate of the gross weight of the vehicle. This estimate is used for various sizing operations such as selecting an appropriately sized engine, main gun, and suspension system. This type of procedure was used in the HESCOMP model [Davis et. al, 1974] in determining helicopter design parameters. Exhibit 15 illustrates the order in which the model processes the various subsystems using an input estimate of gross weight. The exhibit indicates the dependence

EXHIBIT 15: ORDER OF PROCESSING SUBSYSTEMS

Subsystem	Dependencies: Gross Weight	Dependencies: Other Subsystems
1. Armament & Fire Control	X	
2. Power Train	X	
3. Suspension	X	
4. Crew & Cargo		1
5. Structure/Ballistic Protection	X	1, 2, 3, 4, 6*
6. Miscellaneous	X	

*In processing the structure/ballistic protection subsystem the model uses an estimate of 10% of total interior volume and 10% of gross weight for the miscellaneous components.

of each subsystem on other subsystems and on gross vehicle weight. Note that since all subsystems contribute to gross weight and nearly all subsystems are dependent on gross weight, there is a high level of mutual dependence among subsystems.

2.6 Estimation of System Engineering and Performance Characteristics

GENVEH, the main solution routine, calls DIMENS, FPOWER and MOBILE to estimate system engineering and performance attributes. (These attributes were listed in exhibit 4 - see section 2.3.1). Firepower related attributes (i.e., the P_H and $P_{K/H}$ arrays) are computed by FPOWER. Final estimates of all other attributes are computed by DIMENS. MOBILE computes preliminary estimates of mobility attributes using the user-input initial gross weight estimate and then checks to see that mobility constraints are satisfied. If not, it returns a code to GENVEH indicating that another power train should be selected.

2.6.1 Structural Dimensions and Weights

Estimation of the overall dimensions and the weight of the structural components, i.e., the hull and the turret follows, the logic of the OSU "Hardware Interaction Model" [Bishop and Stollmack, 1968]. That model is described in Appendix B to this report. It is implemented by subroutine DIMENS in the model.

Engineering parameters computed by DIMENS include hull and turret lengths, widths and heights; the weights of hull and turret structures; and the gross weight of the vehicle. As noted above, DIMENS also computes the final estimates of mobility and survivability performance parameters.

2.6.2 Estimation of Main Gun Accuracy

Main gun accuracy is estimated in subroutine FPOWER based on a simplified model of contributions to main gun errors, which assumes that the probability of hitting a standard target is:

Prob {Hit|round type, range}

$$= \int_{-1/2\ Y_T}^{1/2\ Y_T} \phi(y|o,\ \sigma_y)dy \int_{-1/2\ X_T}^{1/2\ X_T} \phi(x|0,\sigma_x)dx$$

where:

$\phi(\bullet|\mu;\sigma)$ = Normal probability density function with mean μ and standard deviation σ

X_T, Y_T = Target dimensions (7.5' x 7.5')

σ_x, σ_y = Standard deivation of impact distribution along x- and y-axes, respectively, and

σ_x and σ_y are functions of round type, range, and firepower subsystem component selections, e.g.,

$$\sigma_x\ (\text{rd, range}) = \left[\sum_{i \in FP} \sigma_{xi}^2\ (\text{rd, range}) \right]^{1/2},$$

where:

σ_{xi} (rd, range) = Error contribution of component i for given round and range,

FP = Set of firepower components influencing main gun accuracy.

2.6.3 Estimation of Other Performance Attributes

Many system attributes such as gross horsepower per ton, average ground pressure, maximum width of ditch a vehicle can cross, etc. are computed in a straightforward manner by subroutine DIMENS. For example, maximum ditch width is estimated as one half the distance between the centers of the roller and the drive sprocket (see Appendix B). Estimation of other performance attributes is chiefly accomplished by means of "look-up" table functional relationships. Exhibit 16 lists the look-up table functions used by the model indicating the dependent variable (performance attribute) and the independent variables (engineering characteristics) for each relationship.

2.7 Output Routines

The function of the output routines is to transform the internal description of the concept vehicle into a set of tables displaying the attributes of the generated concept vehicle in formats convenient to the model user. Also output is an echo of the user input specifications.

The output of the concept vehicle is in two tables, table 1 lists the components included in the concept vehicle together with those attributes common to all components. It also indicates the percentage of the total weight and volume represented by each component. Table 2 list has two sections, the first of which has attributes (engineering and performance parameters) for the system as a whole. The second section lists engineering parameters specific to each of the selected components in the concept vehicle. A sample of the model output is presented in chapter 4.0.

EXHIBIT 16: "LOOK-UP TABLE" FUNCTIONAL RELATIONSHIPS

DEPENDENT VARIABLE	INDEPENDENT VARIABLES
ACCELERATION	SPROCKET HP/TON, GROSS WEIGHT
RIDE-LIMITED MAXIMUM ROUGH TERRAIN SPEED	TERRAIN RMS, MAXIMUM ROAD WHEEL TRAVEL, GROSS WEIGHT, TRACK GROUND CONTACT LENGTH, NUMBER OF ROAD WHEELS
MAXIMUM SPEED, HARD SMOOTH SURFACE	SPROCKET HP/TON, SLOPE GRADE
MAXIMUM SLOPE VEHICLE CAN CLIMB	SPROCKET HP/TON, GROSS WEIGHT
FUEL CONSUMPTION (MILES PER GALLON) OVER SPECIFIED COURSE	GROSS HORSEPOWER, SPROCKET HP/TON, TYPE OF ENGINE
PROB (PENETRATION$\vert$HIT ON HULL GLACIS)	GLACIS THICKNESS, RANGE, ASPECT ANGLE, ROUND TYPE, ARMOR TYPE
PROB (PENETRATION$\vert$HIT ON FRONTAL 60° ARC OF TURRET)	FRONTAL TURRET ARMOR THICKNESS, RANGE, ASPECT ANGLE, ROUND TYPE, ARMOR TYPE
PROB (KILL$\vert$HIT OF SPECIFIED THREAT TARGET)	DISPERSION, RANGE, ASPECT ANGLE, ROUND TYPE

3.0 INSTRUCTIONS FOR THE MODEL USER

This chapter contains instructions for operation of the model by the user.

3.1 Input and Output File Specification

The logical units in the FORTRAN code associated with various input and output files are indicated in exhibit 17. (See section 2.3 for descriptions of data base files.)

EXHIBIT 17: LOGICAL UNITS ASSOCIATED WITH INPUT/OUTPUT FILES

Logic Unit Number	File Type	Input/Output
1	"Look-up Table" Functional Relationships Data	Input
2	Reference Vehicles	Input
3	Generic Vehicle File	Input
4	Components File	Input
5	Specification File	Input
6	Comments, Warnings, and Error Messages	Output
7	Generated Concept Vehicle Description	Output
8	Echo of Specifications	Output

3.2 *Making Model Run*

Once a data base has been established and is available on mass storage (e.g., disc, tape, etc.) making a model run involves the following steps.

- Determine the class of vehicle to be investigated.
- Determine whether there exists a Generic Vehicle file for that class (if not, one may have to be generated).
- Determine whether all components of interest are described in the Reference Vehicle or Components files (if not, it may be necessary to update the data base to add components of interest).
- Determine whether specific attributes of components in the data base should be changed (if so, the appropriate attribute values should be changed).
- Determine the set of specifications for the concept vehicle.
- Transform the concept vehicle specifications into a specification file for input on logic unit 5 (see section 3.3 below).
- Run the model with input and output file assignments as indicated in exhibit 17.

3.3 *User Specifications Input File*

The types of information the user must furnish as input are listed in exhibit 18. Six types of records are used. The format for each record type is indicated in exhibit 19. For the first three types there must be exactly one of each type in the file. The first record identifies the vehicle class; the second provides an initial estimate of gross vehicle

EXHIBIT 18: TYPES OF INFORMATION REQUIRED FOR USER SPECIFICATION OF A CONCEPT VEHICLE

- VEHICLE CLASS
- ESTIMATED GROSS WEIGHT
- RELATIVE IMPORTANCE OF FIREPOWER, MOBILITY, PROTECTION, RAM/D, COST
- SPECIFIC COMPONENTS THAT CONCEPT VEHICLE SHOULD CONTAIN
- ENGINEERING PARAMETERS DESCRIBING CONCEPT VEHICLE
- PERFORMANCE PARAMETERS DESCRIBING CONCEPT VEHICLE

EXHIBIT 19: FORM IN WHICH USER SPECIFICATIONS COULD BE INPUT

Record Type	Record Description

1

Record purpose: identify vehicle class
Number records of this type: 1
Record fields:

Columns	Content	Format for Reading Field
1-20	"VEHICLE CLASS"	A4
21-28	Alphanumeric vehicle class identifier	A8

2

Record purpose: provide gross weight estimate
Number records of this type: 1
Record fields:

Columns	Content	Format for Reading Field
1-20	"GROSS WEIGHT" or "WEIGHT"	A4
21-28	Estimated vehicle weight in tons	F8.0

3

Record purpose: provide user's view of importance of various categories of desirability
Number records of this type: 1
Record fields:

Columns	Content	Format for Reading Field
1-20	"EVALUATION" or "DESIRABILITIES"	A4
21-28	Weight for firepower importance	F8.0
29-36	Weight for mobility importance	F8.0
37-44	Weight for protection importance	F8.0
45-52	Weight for RAM/D importance	F8.0
53-60	Weight for cost importance[1]	F8.0

[1]Field not used in this version of the model.

EXHIBIT 19: FORM IN WHICH USER SPECIFICATIONS COULD BE INPUT

(Continued)

Record Type	Record Description
4	Record purpose: to identify either the number of components of a particular type to choose or the specific component of a given type to choose for the concept vehicle Number of records of this type: zero or more Record group identifier: "COMPONENTS" Record fields:

Columns	Content	Format for Reading Field
2-3	Number of components to choose (optional)	I2
5-7	Component code (2-letter code[1])	A3
9-10	Index of specific components (optional)	I2
12-17	Vehicle Name (optional)	A6

Record Type	Record Description
5	Record purpose: to identify engineering parameter constraints associated with particular component types Number of records of this type: zero or more Record group identifier: "ENGINEERING PARAMETERS" Record fields:

Columns	Content	Format for Reading Field
2-4	Component type code, letter + integer (required)	A3
6-13	Input name[1] of attribute of interest (required)	A8
15-16	Relational operator: >, >=, =, ¬=, <, <=, GT,GE,EQ,NE,LT,LE, ≥, ≤, ≠ (required)	A2
18-23	Vehicle name (optional)	A6
25	Multiplication operator ("*") (optional)	A1
27-34	Value (optional)	F8.0
36	Addition operator ("+" or "-")(optional)	A1
38-45	Value (optional)	F8.0
47-48	Component Index (required)	I2

[1]See exhibit 8, 10, and 11 in section 2.4 for component codes and input names of attributes associated with particular component types.

EXHIBIT 19: FORM IN WHICH USER SPECIFICATIONS COULD BE INPUT

(Concluded)

Record Type	Record Description
6	Record purpose: to identify constraints on attributes associated with the concept vehicle system as a whole
	Number of records of this type: zero or more
	Record group identifier: "VEHICLE PARAMETERS"

Record fields:

Columns	Content	Format for Reading Field
2-4	"VEH" (optional)	A3
6-13	Input name[1] of attribute of interest (required)	A8
15-16	"Relational" operator: >, >=, ...GT,GE,... (required)	A2
18-23	Vehicle name (optional)	A6
25	Multiplication operator ("*")(optional)	A1
27-34	Value (optional)	F8.0
36	Addition operator ("+" or "-")(optional)	A1
38-45	Value (optional)	F8.0

[1]See exhibit 9 in section 2.4 for input names associated with attributes of the concept vehicle system as a whole.

weight; and the third supplies a set of weighting factors to be used by the program in computing an "evaluation score" for each component.[1] Each of the first three records has a label in columns 1-20 to identify the record (the program checks only columns 1-4) to verify that the record type is appropriate. The information content of these records is placed in fields beginning after the record label, according to the format indicated in exhibit 19.

The last three types of records are used to identify the user's selection of components, his constraints on engineering parameters, and his constraints on vehicle performance parameters. An arbitrary number of each of these types of records (zero or more) may be used. Each group of records has a special header record to identify the type of records which follow. The header record can be omitted if there are no records of this type included in the user's specifications.

A component record can be used either to specify how many components of a given type there should be in the concept vehicle or to specify a particular choice of a component. In the first case, the type and number fields will be specified and the remaining fields will be blank.

---

[1]Associated with each component are five evaluation measures. The meaning of these measured is arbitrary and can be changed to suit the user's preference. Currently they are identified as measures for: (1) firepower, (2) mobility, (3) protection, (4) RAM/D, and (5) cost. The input routine CSCORE computes the cross product of these measures and the weights input by the user to yield a component score. This score is used by the model to determine the order in which components of a given type will be selected as candidates for incorporation in the concept vehicle. The program tries the component with the highest score first. If it is not satisfactory, it next tries the one with the second highest score, and so on. Thus, the user can control the order of selection of components by assigning evaluation measures to components in the data base and by specifying weighting factors for each evaluation category in the concept vehicle specification file, described here.

Specifying a particular component is handled either by indicating an existing vehicle from which to extract a particular component type or by designating the index of the particular component among the n_i alternatives of component type i. The ordering of particular components within a component type is based on their relative scores (see footnote on previous page.)

The user may also use a component record to select a reference vehicle to be used as a basis for specifying a new concept vehicle. In this case the reference vehicle description will be retrieved from the data base. Further specifications of components, engineering parameters, or performance parameters by the user will be interpreted as overriding the corresponding portions of the initial vehicle description. To use a component record for this purpose a user puts "VEH" in the second field of the record rather than putting a component identifier there. The fourth field of the component record then identifies the vehicle of interest.

Constraints on component engineering parameters (record type 5) and constraints on total vehicle system parameters (record type 6) are each specified in almost the same way. The first difference is that for component parameters one field is set aside to identify the component type that the constraint applies to. For specifying vehicle system parameters (record type 6) this field may be left blank or filled with the character string "VEH". The second difference is that for component parameter specification records (type 5) a component index must be entered in columns 47-48. Conventions for the component index are as follows:
(1) if the specification refers to a component in the Components File, the index of the component in that file should be entered; (2) if the specification refers to a component in the Reference Vehicle File, a value greater than n_i but not more than 50 should be entered, where n_i is the

number of components of type i in the Components File; (3) if the specification does not refer to any component in the data base, a value of 51 or greater should be entered.

For both record types 5 and 6 a constraint is specified in the following form:

"ATTRIBUTE, RELOP, VALUE",

where:

"ATTRIBUTE" denotes the parameter (or attribute) to be constrained. (Input names listed in exhibits 9, 10 and 11 of chapter 2.0 must be used.)

"RELOP" denotes one of the six standard relational operators such as equals, less than, etc. (see exhibit 19.)

"VALUE" denotes the user's choice for the numeric value associated with the relational operator which the attribute must satisfy.

The "VALUE" position of the constraint record can be specified in several different ways. One way is to specify a numeric constant. A second way is to reference the value of the corresponding attribute of a reference vehicle. This reference is accomplished by supplying the vehicle's name (a unique code of six or fewer characters). Optionally, the referenced vehicle's value for this attribute may be multiplied by a constant and/or have a constant added or subtracted from it. Four fields of the record are used to specify such operations. If the value of an attribute is really a vector or array of values (e.g., $P_{hi}t$) rather than a single scalar, then the linear transformation specified by the user is applied to each of these values.

The user can specify multiple constraints on a single attribute. Thus, he could specify a desired range of values for a parameter by specifying both greater and less than constraints.

The user may also specify constraints pertaining to a component which he indicated should specifically be included in the concept vehicle. Each added constraint would be viewed as overriding the specific value of the component's particular attribute indicated. This allows the user to easily tell the program, "choose component x but increase the value of parameter y by at least z percent."

Exhibit 20 is a sample user specification input file. This file specifies hull, turret 1, main gun 2, and engine 4 in the Components File. It also specifies a weight constraint on the hull and a volume constraint on the turret in the ENGINEERING PARAMETERS section. In the VEHICLE CHARACTERISTICS section, constraints are on the total weight (less than the weight of the M60A1 plus ten percent) and on the total volume (less than 650 cubic feet).

EXHIBIT 20: SAMPLE USER SPECIFICATION INPUT FILE

```
VEHICLE CLASS        TANKS
WEIGHT               50.
EVALUATION           1.       1.       1.       1.       1.
COMPONENTS
    HL   1
    TU   1
    GU   2
    EN   4
ENGINEERING PARAMETERS
 HL  WEIGHT   LE M60A1                        31
 HL  VOLUME   LE M60A1                        30
 TR  X7       LE M60A1  * 1.2                 35
VEHICLE CHARACTERISTICS
     WEIGHT   LT M60A1  * 1.1
     VOLUME   LT          650.
```

4.0 TEST RUN RESULTS

This chapter provides examples of model outputs produced by test runs. Section 4.1 discusses the test data base. Section 4.2 discusses two test runs, and section 4.3 displays the complete set of outputs for one of the test runs.

4.1 Test Data Base

Before test runs could be made a test data base was needed. For this purpose the following files were created using data generated to test the logic of the model. In cases where data needed could not be found, judgmental estimates were entered.

- A Generic Vehicle File for conventional tanks, using M60A3 data, where available to the project team, as the default parameter values for attributes of the system as a whole and for components of the system.
- A Reference Vehicle File with one vehicle having M60A3 data and two hypothetical vehicles having assumed attributes different from the M60A3.
- A Components File with M60A3 and XM1 components and several hypothetical components, such as an advanced technology 1100 HP diesel engine smaller and lighter than the 750 HP ADVS-1970 engine of the M60A3.

- A Functional Relationships look-up table data file. Estimates for values entered in these tables were based on a sampling of outputs of TARADCOM system performance models (e.g., Power-Train Model and V-Ride Model) obtained from TARADCOM personnel and on data found in a variety of references, including [Criswell, et. al, 1977], [Sloss, et. al, 1977], [Lee and Williams, 1977], [Battelle, 1977], [Battelle, 1969], [Bishop and Stollmack, 1968], and [Owen, et. al, 1963]. Some data, such as the Probability of Kill Given a Hit table were judgmental estimates.

4.2 Test Runs

Two test runs will be discussed. For the first, designated run A, the inputs shown in exhibit 21 specified the components of the M60A3.[1] (Recall that certain structural parameters of the hull and turret are "open" and must be computed, as discussed in chapter 2.0). The model then produced estimates of overall structural dimensions, structural weights (hull and turret), gross vehicle weight, and system performance characteristics. The results of this run are summarized in exhibit 22.

Test run B was the same as test run A, except that the power train was not specified and a required road speed of 40 MPH or greater was specified as shown in the Components File included:

- Engines:
  - AVDS-1790: 750 gross HP, 640 net HP
    (standard M60A3 engine)

---

[1] In the Components File each component from the M60A3 happened to be assigned the index 1.

EXHIBIT 21: INPUT USER SPECIFICATION FILE FOR TEST RUN A

```
VEHICLE CLASS        TANKS
WEIGHT               55.
EVALUATION           1.       1.       1.       1.       1.
COMPONENTS
     HL    1
     TU    1
     GU    1
     MG    1
     AD    1
     RA    1
     SN    1
     ST    1
     GC    1
     AM    1
     AS    1
     EN    1
     TR    1
     FD    1
     RW    1
     SD    1
     TK    1
     FU    1
     FT    1
     CR    1
     CG    1
     EL    1
     CM    1
     FE    1
     EC    1
     SG    1
ENGINEERING PARAMETERS
VEHICLE CHARACTERISTICS
```

EXHIBIT 22: SUMMARY OF OUTPUTS FOR TEST RUN A

ATTRIBUTES	MODEL ESTIMATE	KNOWN VALUES
STRUCTURAL		
GROSS WEIGHT	112,770 LB	113,600
HEIGHT (TURRET ROOF)	105 IN	107
WIDTH	147 IN	143
LENGTH (HULL)	282 IN	273
TRACK GROUND CONTACT	158 IN	167
MOBILITY		
GROSS HP/TON	13.3	13.2
SPROKET HP/TON	8.1	7.8
GROUND PRESSURE	12.7 PSI	12.2 PSI
MAX WIDTH DITCH	9.2 FT	8.5 FT
ROAD SPEED	30.5 MPH	30.0 MPH
30% SLOPE SPEED	4.5 MPH	4.2 MPH
MAX SLOPE	59%	60%
ACCELERATION 0-20 MPH	15 SEC	16 SEC
RIDE LIMITED SPEED		
1.5 RMS TERRAIN	20 MPS	22 MPS
2.5 RMS TERRAIN	17 MPS	18 MPS

--continued on next page--

EXHIBIT 22: SUMMARY OF OUTPUTS FOR TEST RUN A

(Concluded)

FIREPOWER PERFORMANCE	MODEL ESTIMATES*
P(HIT/KE RD, STD TGT)	
1000 M	.91
2000 M	.42
3000 M	.19
P(KILL/HIT, T62, 0°)	
1000 M	.60
2000 M	.40
3000 M	.20
SURVIVABILITY	
P(KILL/HIT, 115 MM KE, 0°)	
1000 M	.8
2000 M	.5
3000 M	.2

*BASED ON JUDGMENTAL ESTIMATES FOR FIRE CONTROL ACCURACY ERRORS AND $P_{K/H}$ "LOOK-UP" TABLE VALUES.

EXHIBIT 23: INPUT USER SPECIFICATION FILE FOR TEST RUN B

```
VEHICLE CLASS         TANKS
WEIGHT                55.
EVALUATION            1.       1.       1.       1.       1.
COMPONENTS
     HL   1
     TU   1
     GU   1
     MG   1
     AD   1
     RA   1
     SN   1
     ST   1
     GC   1
     AM   1
     AS   1
     RW   1
     SD   1
     TK   1
     CR   1
     CG   1
     EL   1
     CM   1
     FE   1
     EC   1
     SG   1
ENGINEERING PARAMETERS
VEHICLE CHARACTERISTICS
      MX SPEED GE           40.0
```

- SOA-1100: "conceptual" state-of-the-art deisel; 1100 gross HP, 1000 net HP, smaller, lighter than ADVS-1970.
- AGT-1500: 1500 gross HP, 1470 net HP, (XM1 engine)

- Transmissions:
  - CD-850: 750 HP maximum input
  - X1100: 1500 HP maximum input

The results of test run B are summarized in exhibit 24. Only structural and mobility attributes are displayed. The firepower and survivability performance estimates were the same as for test run A. In order to meet the mobility requirement the model selected the more powerful SOA-1100 engine. Also since the CD-850 has a maximum input horsepower capacity of 750 HP, the model selected the X1100 transmission, which was the only one in the data base capable of handling 1100 input horsepower. Although the SOA-1100 engine is conjectured to be slightly smaller than the ADVS-1790, the SOA-1100/X1100 combination is slightly larger than the ADVS-1790/CD-850 power pack. Thus, the estimates produced for dimensions and weights indicate the vehicle is slightly longer and heavier than was the case for test run A. The estimates of vehicle mobility performance indicate that the vehicle met the requirement of a 40 MPH road speed.

4.3 Sample Outputs

Output tables produced by the model for test run A are reproduced in exhibits 25 and 26. Exhibit 25 is Table I which lists all the components

EXHIBIT 24: SUMMARY OF OUTPUT FOR TEST RUN B

ENGINE/TRANSMISSION SELECTED: SOA-1100/X1100

ATTRIBUTES	RUN B	RUN A
STRUCTURAL		
GROSS WEIGHT	113,609 LB	112,770 LB
HEIGHT (TURRET ROOF)	105 IN	105 IN
WIDTH	147 IN	147 IN
LENGTH (HULL)	291 IN	283 IN
TRACK GROUND CONTACT	164 IN	158 IN
MOBILITY		
GROSS HP/TON	19.4	13.3
SPROKET HP/TON	12.6	8.1
GROUND PRESSURE	12.3 PSI	12.7 PSI
MAX PITCH WIDTH	9.7 FT	9.4 FT
ROAD SPEED	41.2 MPH	30.5 MPH
MAX SLOPE	62%	59%
30% SLOPE SPEED	7.0 MPH	4.5 MPH
ACCELERATION 0-20 MPH	7 SEC	15 SEC
RIDE LIMITED SPEED		
1.5 RMS TERRAIN	20 MPH	20 MPH
2.5 RMS TERRAIN	17 MPH	17 MPH

EXHIBIT 25: MODEL OUTPUT TABLE 1

TABLE 1A: CONCEPT VEHICLE: ATTRIBUTES IN COMMON TO ALL COMPONENTS

	------- IDENTIFICATION	-------			PRODUCIBILITY	
SUBSYSTEM / COMPONENT	NATION	MANUF	MODEL	COMP INDX	# PROD	R&D TIME
A. STRUCTURE/BALLISTIC PROT						
1. HULL(W/DECK GRILLS)	USA	CHRYSLER	M60	1	10000	0.0
2. TURRET(W/CUPOLA)	US	CHRYSLER	M60A3	1	5000	0.0
3. ARMOR SKIRTS				0	0	0.0
B. ARMAMENT & FIRE CONTROL						
1. MAIN GUN & MOUNT	US	GFE	M68	1	6000	0.0
2. COAX MACHINE GUN	USA		M240	1	300	0.0
3. LOADER'S GUN				0	0	0.0
4. COMMANDER'S/AD GUN	USA	.	M85	1	6000	0.0
5. RANGING SYSTEM	USA		AN/VVG-2	1	0	0.0
6. SENSING/SIGHTING SYS				1	6000	0.0
7. STABLIZATION SYSTEM				1	1000	0.0
8. GUN CNTL(ELEV/TRVRS)				1	6000	0.0
9. AMMUNITION				1	6000	0.0
10. AMMO STORAGE				1	6000	0.0
C. POWER TRAIN						
1. ENGINE	USA	TELEDYNE	AVDS1790	1	1000	0.0
2. TRANSMISSION	USA	GMC	CD8506A	1	3000	0.0
3. FINAL DRIVE	USA	CHRYSLER	COAX	1	2500	0.0
4. FUEL				1	6000	0.0
5. FUEL CONTAINER SYS				1	6000	0.0
D. SUSPENSION/SKIRTS						
1. ROAD WHEELS, ETC.	US			1	3	0.0
2. SPRINGING & DAMPING	US	4350H		1	3500	0.0
3. TRACK			T142	1	1	0.0
E. CREW & CARGO						
1. CREW				1	0	0.0
2. CARGO				1	6000	0.0
F. MISCELLANEOUS						
1. ELECTRICAL SYSTEM				1	6000	0.0
2. COMMUNICATIONS				1	6000	0.0
3. FIRE EXTINGUISHER				1	6000	0.0
4. ENVIRON CONDIT, CBR				1	6000	0.0
5. DIAGNOSTIC SYSTEM				0	0	0.0
6. SIGNATURE SUPRES SYS				0	0	0.0
7. SMOKE GENERATION SYS				1	6000	0.0
8. AUTO DEF SYS				0	0	0.0

EXHIBIT 25: MODEL OUTPUT TABLE 1

(Concluded)

TABLE 1B: CONCEPT VEHICLE: ATTRIBUTES IN COMMON TO ALL COMPONENTS

SUBSYSTEM / COMPONENT	NUMBER	WEIGHT LBS	WEIGHT PERCENT	INTERNAL VOLUME CU FT	INTERNAL VOLUME PERCENT	R A M / D MAINT/OP	R A M / D MATURITY	R A M / D CMPLXITY	R A M / D MMBF
A. STRUCTURE/BALLISTIC PROT									
1. HULL(W/DECK GRILLS)	1	33066.66	29.3	455.3	N/A	0.0	5	1	6000.0
2. TURRET(W/CUPOLA)	1	19958.35	17.7	311.0	N/A	0.0	5	1	6000.0
3. ARMOR SKIRTS	0	0.0	0.0	0.0	0.0	0.0	0	0	0.0
B. ARMAMENT & FIRE CONTROL									
1. MAIN GUN & MOUNT	1	2475.00	2.2	20.5	2.6	0.1	5	1	2000.0
2. COAX MACHINE GUN	1	28.00	0.0	0.0	0.0	0.0	0	0	0.0
3. LOADER'S GUN	0	0.0	0.0	0.0	0.0	0.0	0	0	0.0
4. COMMANDER'S/AD GUN	1	65.00	0.1	0.0	0.0	0.0	0	0	0.0
5. RANGING SYSTEM	1	20.00	0.0	1.0	0.1	0.0	0	0	0.0
6. SENSING/SIGHTING SYS	1	20.00	0.0	1.0	0.1	0.0	0	0	0.0
7. STABLIZATION SYSTEM	1	75.00	0.1	2.0	0.3	0.0	0	0	0.0
8. GUN CNTL(ELEV/TRVRS)	1	50.00	0.0	2.0	0.3	0.0	0	0	0.0
9. AMMUNITION	1	3000.00	2.6	150.0	19.6	0.0	0	0	0.0
10. AMMO STORAGE	1	150.00	0.1	30.0	3.9	0.0	0	0	0.0
C. POWER TRAIN									
1. ENGINE	1	5000.00	4.4	164.0	21.4	0.9	5	2	1394.0
2. TRANSMISSION	1	3025.00	2.6	39.0	5.1	1.0	5	2	350.0
3. FINAL DRIVE	1	1500.00	1.3	6.0	0.8	1.0	4	2	350.0
4. FUEL	1	2918.00	2.6	51.3	6.7	0.0	0	0	0.0
5. FUEL CONTAINER SYS	1	200.00	0.2	56.3	7.3	0.0	0	0	0.0
D. SUSPENSION/SKIRTS									
1. ROAD WHEELS, ETC.	1	10250.00	9.1	0.0	0.0	1.1	1	1	10.0
2. SPRINGING & DAMPING	1	6040.00	5.4	0.0	0.0	1.0	5	1	10.0
3. TRACK	1	12080.00	10.7	0.0	0.0	1.0	3	1	1.5
E. CREW & CARGO									
1. CREW	1	1140.00	1.0	160.0	20.7	0.0	5	3	0.0
2. CARGO	1	700.0	0.6	10.0	1.3	0.0	0	0	0.0
F. MISCELLANEOUS									
1. ELECTRICAL SYSTEM	1	300.00	0.3	15.0	2.0	0.0	0	0	0.0
2. COMMUNICATIONS	1	100.00	0.1	5.0	0.7	0.0	0	0	0.0
3. FIRE EXTINGUISHER	1	20.00	0.0	20.0	2.6	0.0	0	0	0.0
4. ENVIRON CONDIT, CBR	1	68.50	0.1	3.0	0.4	0.0	0	0	0.0
5. DIAGNOSTIC SYSTEM	0	0.0	0.0	0.0	0.0	0.0	0	0	0.0
6. SIGNATURE SUPRES SYS	0	0.0	0.0	0.0	0.0	0.0	0	0	0.0
7. SMOKE GENERATION SYS	1	0.0	0.0	0.0	0.0	0.0	0	0	0.0
8. AUTO DEF SYS	0	0.0	0.0	0.0	0.0	0.0	0	0	0.0
9. MISC SYSTEMS/ COMPS	0	11276.90	0.1	30.2	4.1	0.0	0	0	0.0
CONCEPT VEHICLE	1	112769.60	100.0	766.3	100.0	7.1	3	1	1.1

incorporated in the vehicle and displays the associated common attributes for each component. Section B of Table 1 also shows the percentages of the total volume and weight of the vehicle represented by each component.

Exhibit 26 reproduces Table 2 of the model outputs. The first section of this table displays the attributes of the system as a whole as estimated by the model. The second section displays the values of the engineering parameters specific to each component for the selected set of components.

EXHIBIT 26: MODEL OUTPUT TABLE 2

System Attributes

A. STRUCTURAL		
1. WEIGHT	112769.60	LB
2. VOLUME	766.33	FT3
3. HEIGHT	104.75	IN
4. WIDTH	147.15	IN
5. LENGTH	282.02	IN
6. LENGTH/TRSPD	1.32	-
7. TRACK GRD CONTACT	158.24	IN
B. FIREPOWER		
1. P HIT, STAT FIRER		
KE ROUND		
STATIONARY		
1000 M	0.91	-
2000 M	0.42	-
3000 M	0.19	-
MOVING		
1000 M	0.57	-
2000 M	0.24	-
3000 M	0.13	-
HEAT ROUND		
STATIONARY		
1000 M	0.82	-
2000 M	0.32	-
3000 M	0.07	-
MOVING		
1000 M	0.39	-
2000 M	0.19	-
3000 M	0.04	-
2. P HIT, MOVE FIRER		
KE ROUND		
STATIONARY		
1000 M	0.57	-
2000 M	0.34	-
3000 M	0.13	-
MOVING		
1000 M	0.44	-
2000 M	0.21	-
3000 M	0.05	-
HEAT ROUND		
STATIONARY		
1000 M	0.46	-
2000 M	0.29	-
3000 M	0.08	-
MOVING		
1000 M	0.34	-
2000 M	0.17	-
3000 M	0.02	-
3. P KILL GIVEN HIT		
KE ROUND		
0 DEG		
1000 M	0.60	-
2000 M	0.40	-
3000 M	0.20	-
90 DEG		
1000 M	0.90	-
2000 M	0.75	-
3000 M	0.60	-
HEAT ROUND		

EXHIBIT 26: MODEL OUTPUT TABLE 2

(Continued)

0 DEG		
1000 M	0.60	-
2000 M	0.60	-
3000 M	0.60	-
90 DEG		
1000 M	0.90	-
2000 M	0.90	-
3000 M	0.90	-
C. MOBILITY		
1. GROSS HP / TON	13.30	HP/T
2. SPROCKET HP / TON	8.13	HP/T
3. AV GRD PRESSURE	12.74	PSI
4. MAX HEIGHT OBSTACLE	3.00	FT
5. MAX WIDTH DITCH	10.32	FT
6. MAX DEPTH WATER	4.00	FT
7. MAX DEP WATER, PREP	8.00	FT
8. MAX ROAD SPEED	30.49	MPH
9. MAX SPEED, 30 PC SLP	4.51	MPH
10. RANGE (PROT FUEL)	339.43	MI
11. RANGE (ALL FUEL)	339.43	MI
12. ACCELERATION, 0-20	14.98	SEC
13. MAX SLOPE CLIMB	59.42	-
14. TURN RATE (PIVOT)	5.00	RPM
15. TURN RADIUS	0.0	FT
16. BRAKING DIST, 30MPH	103.70	FT
17. MAX SLOPE, PARK	30.00	-
18. AV SPEED, TERRAIN 1	20.00	MPH
19. AV SPEED, TERRAIN 2	17.00	MPH
20. WT / LINEAL FT	1.55	T/FT
D. PROTECTION		
1. P PENETR'N OF HIT		
KE ROUND		
0 DEG		
1000 M	0.80	-
2000 M	0.50	-
3000 M	0.20	-
90 DEG		
1000 M	0.90	-
2000 M	0.80	-
3000 M	0.60	-
HEAT ROUND		
0 DEG		
1000 M	0.85	-
2000 M	0.85	-
3000 M	0.85	-
90 DEG		
1000 M	0.95	-
2000 M	0.95	-
3000 M	0.95	-
E. RAM/D		
1. MATURITY INDEX	5.00	-
2. COMPLEXITY INDEX	2.00	-
3. RELIABILITY MEAS	130.00	MI
4. MAINT HRS/OP HRS	1.00	-
F. COST		
1. ACQ COST	0.0	$
2. OPERATING COST	0.0	$

EXHIBIT 26: MODEL OUTPUT TABLE 2

(Continued)

Component Engineering Parameters

HULL		HL		
	HEIGHT		50.05	IN
	LENGTH		282.02	IN
	WIDTH		91.15	IN
	ARMOR TYPE		1	-
	THICKNESS SIDE ARMOR		2.00	IN
	THICKNESS REAR ARMOR		1.50	IN
	THICKNESS UPPER GLACIS		4.00	IN
	THICKNESS LOWER GLACIS		4.00	IN
	THICKNESS FRONT DECK		3.00	IN
	THICKNESS REAR DECK		1.00	IN
	THICKNESS BOTTOM		0.75	IN
	UPPER GLACIS OBLIQUITY		64.00	DEG
	LOWER GLACIS OBLIQUITY		45.00	DEG
	LOWER REAR OBLIQUITY		45.00	DEG
	LENGTH DRIVERS COMPART		57.00	IN
	DRV SEAT - TURRET RING		1.00	IN
	TURRET RING DIAMETER		85.00	IN
	TURRET RING - ENGINE		0.0	IN
	FLOOR- TURRET PLATFORM		17.00	IN
	TURRET PFRM - CEILING		67.50	IN
	HEIGHT DRIVER CMPT		37.01	IN
TURRET		TU		
	HEIGHT		37.08	IN
	LENGTH		121.89	IN
	WIDTH (TURRET PLTFRM)		82.00	IN
	ARMOR TYPE		1	-
	MAIN GUN - SIDE DEST		29.50	IN
	CLEARANCE, PFRM - RING		3.00	IN
	FRONT DECK - MA AXIS		16.00	IN
	REAR DECK - MA AXIS		5.00	IN
	TURRET AXIS - FRT EDGE		75.00	IN
	TURRET AXIS - TRUNNION		42.50	IN
	THICKNESS FRONT ARMOR		5.00	IN
	THICKNESS SIDE ARMOR		2.00	IN
	THICKNESS BOTTOM ARMOR		1.00	IN
	THICKNESS BACK ARMOR		2.00	IN
	THICKNESS CEILNG ARMOR		1.25	IN
MAIN GUN		GU		
	MUZZLE VELOCITY		4800.00	FT/S
	TUBE LEN (CALIBERS)		210.50	IN
	CALIBER		105.00	MM
	ALLOWABLE AMMO TYPES		1	-
	BORE TYPE		1	-
	LOADING TYPE		1	-
	TIME TO FIRE 1ST RD		6.00	SEC
	TIME TO FIRE SUBS RDS		9.00	SEC
	FIRE RATE, AIMED GUN		0.15	/SEC
	MAX ELEVATION		20.00	DEG
	MAX DEPRESSION		-10.00	DEG
	MIN VEHICLE WEIGHT		31.00	TON
	HALF WIDTH OF BREECH		11.50	IN
	TRUNNION - REAR BREECH		59.50	IN
	LENGTH LONGEST ROUND		36.80	IN
	OUTSIDE DIAM OF GUN		5.00	IN
MACH GUN		MG		
	MUZZLE VELOCITY		2800.00	FT/S
	TUBE LEN (CALIBERS)		24.00	-

EXHIBIT 26: MODEL OUTPUT TABLE 2

(Continued)

CALIBER		7.62	MM
ALLOWABLE AMMO TYPES		1	-
BORE TYPE		1	-
LOADING TYPE		1	-
TIME TO FIRE 1ST RD		0.0	SEC
TIME TO FIRE SUBS RDS		0.13	SEC
FIRE RATE, AIMED GUN		8.00	/SEC
COVER FOR FIRER		1.00	-
HORIZ MOVE CONSTRAINTS		0.0	DEG
MAX ELEVATION		0.0	DEG
MAX DEPRESSION		0.0	DEG
MIN VEHICLE WEIGHT		1.00	TON
MISILE L	ML		
AD GUN	AD		
MUZZLE VELOCITY		3000.00	FT/S
TUBE LEN (CALIBERS)		0.0	-
CALIBER		12.70	MM
ALLOWABLE AMMO TYPES		0	-
BORE TYPE		0	-
LOADING TYPE		0	-
TIME TO FIRE 1ST BURST		0.0	SEC
TIME TO FIRE SUBS BRST		0.0	SEC
FIRE RATE, AIMED GUN		875.00	/SEC
COVER FOR FIRER		1.00	-
HORIZ MOVE CONSTRAINTS		360.00	DEG
MAX ELEVATION		60.00	DEG
MAX DEPRESSION		-15.00	DEG
MIN VEHICLE WEIGHT		1.00	TON
RNG SYS	RA		
TYPE		2	-
RANGING ACCURACY		10.00	M
SENSORS	SN		
TYPE		1	-
PERSONS APPLICAPLE TO		1	-
ANGLE OF VIEW		45.00	DEG
MAGNIFICATION		0	-
EFFECTIVE RANGE			
DAY			
DETECT		3000.00	M
RECOGNIZE		1500.00	M
IDENTIFY		4800.00	M
NIGHT			
DETECT		2000.00	M
RECOGNIZE		2700.00	M
IDENTIFY		3100.00	M
STAB SYS	ST		
TYPE		2	-
PERFORMANCE CATEGORY		2	-
GUN CNTL	GC		
TYPE		0	-
PERFORMANCE CATEGORY		1	-
AMMO	AM		
TYPE		0	-
NO. RDS CARRIED		0	-
CALIBER		105.00	MM
GUIDANCE SYSTEM		0	-
AMMO STO	AS		
ENGINE	EN		
TYPE		1	-
HORSEPOWER		750.00	HP

EXHIBIT 26: MODEL OUTPUT TABLE 2

(Continued)

COOLING REQUIREMENTS		110.00	HP
FUEL REQTS, NORMAL		1	-
FUEL REQTS, EMERGENCY		2	-
TRANSMISSION REQTS		3	-
STARTING TIME		2.50	SEC
MIN STARTING TEMP		-10.00	DEGF
MIN START TEMP, AIDS		-30.00	DEGF
LENGTH		74.00	IN
WIDTH		87.75	IN
HEIGHT		43.70	IN
CLEARANCE TO REAR DECK		11.80	IN
CLEARANCE TO SIDEWALL		12.70	IN
TRANSMIS	TR		
TYPE		4	-
EFFICIENCY (% HP OUT)		80.00	-
NO FWD GEARS		2	-
NO RVS GEARS		1	-
LENGTH		30.00	IN
WIDTH		53.50	IN
CLEARANCE TO REAR WALL		17.00	IN
TRANSMISSION KEY		3	-
FIN DRIV	FD		
TYPE		1	-
EFFICIENCY (% HP OUT)		98.00	-
LENGTH		23.30	IN
ROAD WH (INCLUDES RD WHLS, SPRKTS, IDLERS & RETURN ROLLERS)	RW		
NO. ROAD WHEELS/SIDE		6	-
NO. RETURN WHEELS		3	-
DIAMETER OF RD WHEELS		26.00	IN
DRIVE SPROCKET DIAM		24.50	IN
FRONT IDLER DIAMETER		26.00	IN
HEIGHT OF SPROCKET		24.00	IN
HEIGHT OF IDLER		20.50	IN
GROUND CLEARANCE		18.25	IN
LEAD ANGLE OF TRACK		34.75	DEG
TRAILING ANGLE TRACK		44.50	DEG
SPR DAMP (INCLUDES ROAD ARMS)	SD		
MAX WHEEL TRAVEL		8.00	IN
PERFORMANCE CLASS		1	-
TYPE OF DAMPING		1	-
TYPE OF SPRINGING		1	-
DYN SUSP ADJUSTMENT		1	-
TRACK	TK		
TYPE		2	-
MATERIAL		1	-
WIDTH		28.00	IN
THICKNESS		4.52	IN
SKIRTS	SK		
FUEL	FU		
TYPE		1	-
QUANTITY		389.00	GAL
FUEL TNK	FT		
CAPACITY		389.00	GAL
CREW	CR		
NUMBER		4	-
CARGO	CG		
ELEC SYS	EL		

EXHIBIT 26: MODEL OUTPUT TABLE 2

(Concluded)

```
     TYPE                                   0     -
COMMO                    CM
     TYPE                                   0     -
     RANGE OF BROADCAST                   0.0     FT
FIRE EX                  FE
     TYPE SYSTEM FOR CREW                   0     -
     TYPE SYS FOR ENGINE                    0     -
ENVR SYS                 EC
  (INCLUDING NBC PROTECTION)
     TYPE SYSTEM                            0     -
DIAG SYS                 DS
SIGN SUP                 SS
  (SIGNATURE SUPPRESSION COM
SMOK GEN                 SG
     TYPE                                   0     -
EW SYS                   EW
```

APPENDIX A

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Appendix B

ESTIMATION OF VEHICLE DIMENSIONS AND STRUCTURAL WEIGHTS

This appendix defines the relationship used in the Parametric Engineering System Definition Model for estimating vehicle dimensions and structural weights. It is extracted from A.E. Bishop and S. Stollmach (eds.), *The Tank Weapon System,* Report No. RF-573, AR68-1 (U), System Research Group, The Ohio State University, September 1968. The material reproduced here originally appeared as chapter 9 by R. Lawson in the referenced report.

A METHODOLOGY FOR PREDICTING OVERALL DIMENSIONS AND GROSS WEIGHT

by
R. Lawson

Introduction

Overall vehicle dimensions, such as height, length, width, and weight are required before system performance characteristics, such as mobility and protection, can be predicted by other Design Models. These dimensions are not known at the time QMR's are being prepared. What may be known at this time is a potential list of new components to be included in the system and a general design concept or configuration.

The Hardware Interaction Model provides the methodology by which the required overall dimensions can be predicted from the given set of components and an assumed basic configuration. Vehicle dimensions predicted using this model can be compared with constraints related to air transportability, desired crusing range, and mobility (horsepower per ton, track ground pressure, etc.) requirements, etc., to judge the feasibility of a proposed design during initial stages of candidate selection. These predictions should not be used to generate specific designs of future vehicles, since they are based on an extrapolation of trends in past designs. Basically, the methodology provides a means of

estimating the inputs used by the Design Models (Howland and Clark, 1966) to predict mobility, firepower, protection, and acquisition performance of a candidate vehicle.

Relationships of a general nature, common in the literature, such as, "a good estimate of the overall vehicle width is 90 inches plus the magnitude of the gross vehicle weight in tons" (Bekker, 1956) were deemed unsatisfactory for purposes of this study. Such general relationships do not reflect the effect of component sizes and shapes on overall dimensions. Several relationships for estimating vehicle component weights as functions of their characteristics were found in the literature (Owen, et al., 1963; Lockheed Report No. LMSC-B007500, 1965) and have been incorporated into the methodology presented in this chapter.

The remainder of this section of this chapter is devoted to a description of the configuration of a "conventional tank." It was necessary to assume such a configuration throughout this discussion in order to exhibit use of the methodology in predicting overall dimensions. The remainder of this chapter is devoted to the prediction of vehicle width, length, height, weight, and a discussion of mobility performance measures directly related to the vehicle's size and weight. These dimensions are described as sums of sets of independent variables which most often represent component dimensions. Average values of the independent (or component) variables for some past vehicles satisfying the following description of the "conventional" tank are presented in each section. These average values could be taken as values of the independent

variables when predicting the dimensions of a proposed conventional-type vehicle if no other information were available. In some cases, dependencies of these variables on other characteristics, such as the engine size dependence on required horsepower, are indicated.

The Conventional Tank

Relationships between component sizes and weights and between vehicle dimensions and gross weight must be based upon a general configuration. For example, the effect of the size of the power plant on the overall width of the vehicle depends upon its location and orientation within the hull. Thus, in order to illustrate the use of the methodology presented in this report we define a "conventional" tank or M60-like vehicle as follows.

A conventional tank is characterized by the following factors: 1) the crew is composed of a driver, a main gun loader, a main gun gunner, and a tank commander; 2) the driver's position in the vehicle is centered laterally within the hull forward of the turret fighting compartment; 3) the tank commander, main armament gunner, and the main armament loader are located within the turret fighting compartment; 4) the main armament system is trunnion mounted within a rotatable turret; and 5) the power train system is located within the hull behind the turret fighting compartment.[1]

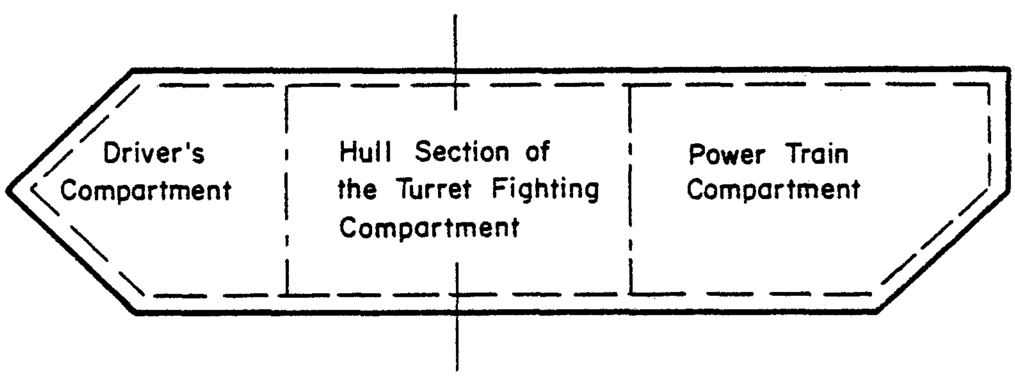
A group of tank vehicles which conform to our definition of a conventional tank are the M551, M60, M48, and M41A1 tanks. An example of a

[1]Additional, more detailed, characteristics of the conventional tank will be given in the appropriate sections of this chapter which follow.

contemporary vehicle which does not conform to our definition of a conventional tank is the M103 heavy combat tank. This vehicle is unusual in that it employs two loaders for the main armament system and both the gunner's and the tank commander's stations are located in the turret bustle.

The vehicle hull (less suspension system) of the conventional tank is shown in Figure 63. In conjunction with Figure 63, the following assumptions are made: 1) the various armored surfaces of the hull are represented by plane surfaces; and 2) the armor over each of the various surfaces of the hull is assumed to be of uniform thickness (on each surface).

In the following sections we discuss the development of prediction equations for the overall dimensions and gross weight of a conventional tank. First we describe the overall dimensions (width, length, and height) of a proposed conventional tank in terms of the dimensions of the major components housed



Sketch Showing Assumed Layout of a Conventional Tank Hull

Figure 63

within the hull and turret. Then, the overall dimensions are used to determine the weight of the armor. The gross weight of the vehicle is then taken to be the sum of the weights of the hull and turret armor, the weights of the major components housed within the hull and turret, and the weight of the suspension system.

In conjunction with the overall vehicle (hull) length estimation equation presented in this report, an equation for estimating the ground-contact-length of the tracks is presented. This length is necessary for the estimation of the ground pressure and the length-to-tread ratio for the proposed vehicle.

Overall Vehicle Width

Approach

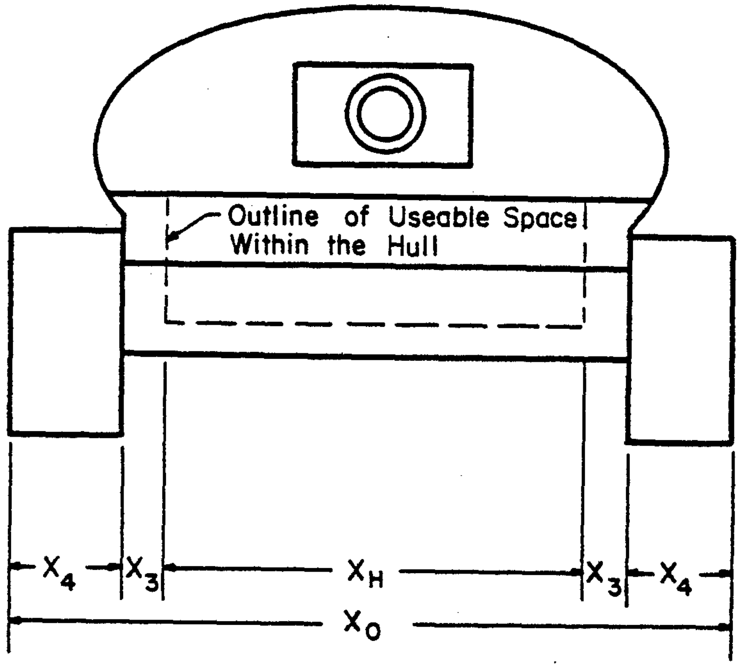
The overall vehicle width (see Figure 64) is determined by the internal hull width X_H, the hull side-armor thickness X_3, and the track width X_4. From Figure 64 we see that the overall vehicle width X_0 can be represented in equation form as [1]

$$X_0 = X_H + 2X_3 + 2X_4. \tag{1}$$

The hull width X_H, in equation 1, in turn, is dependent on the turret or the power train width, whichever is larger.

---

[1] Implicit in the statement of this equation is the assumption that the clearance between the outer hull and the tracks is negligible. Since the overall width of conventional tanks is normally in excess of 100 inches, such as assumption will not introduce a significant error in the vehicle width prediction.

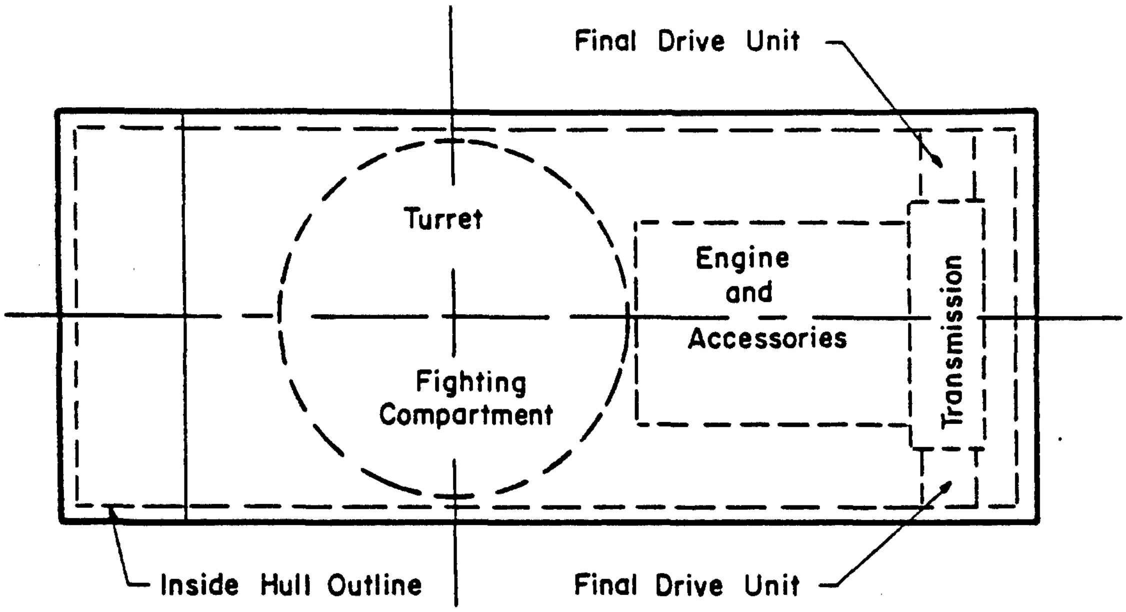


Overall Tank Width Broken Down into Component Widths

Figure 64

The positioning of the turret and power train within the hull of a conventional tank is illustrated by Figure 65 . From this schematic (Figure 65) one can see that the hull width X_H is determined by either the turret platform or the power train (the engine plus its accessories, as illustrated in Figure 65 , or by the transmission and final drive units). The turret platform must be large enough to provide working space, maintenance areas, and meet the safety requirements of the crew. On the other hand, for a given design state-of-the-art, the size of the power train[1] is determined by the types of components used

[1]The power train system consists of the engine, transmission, final drive units, fuel system, and the various power train accessories (batteries, generator, etc.).



Positions of the Turret Fighting Compartment and the Power Train Elements in the Hull of the Conventional Tank

Figure 65

(e.g., a diesel engine, a turbine, etc.) and the horsepower requirements. Relationships between the turret platform and the power train widths and the location and dimensions of certain components and areas (for maintenance, safety, etc.) are given below. Values of these latter dimensions for some past tanks are analyzed in terms of their applicability to predicting the width of a proposed conventional-type tank vehicle. [1]

---

[1] Data on independent (component and area) dimensions for past tanks are presented throughout this chapter. These data should not be used, exclusive of judgment and new component information, as representative values of the corresponding independent variables. In most cases, for example, no information is available concerning the degree to which a particular component dimension was reduced or minimized in an effort to reduce an overall tank dimension. In addition, when new components are added, efforts may be expended, for the first time, to reduce the size of a certain component which now has become critical. Wherever possible, comments are made concerning the degree to which the data presented could be considered as being representative of a future conventional-type tank.

The Turret Fighting Compartment Diameter

A plan view of the turret fighting compartment of a conventional tank is shown in Figure 66. In this figure, X_1 is the horizontal distance between the gunner's guard and the centerline of the main armament (MA) tube (also the turret platform centerline), X_2 is the remaining portion of the turret platform radius, and X_{tp} is the turret platform diameter; space not labeled is required for crew passage and maintenance accessibility.

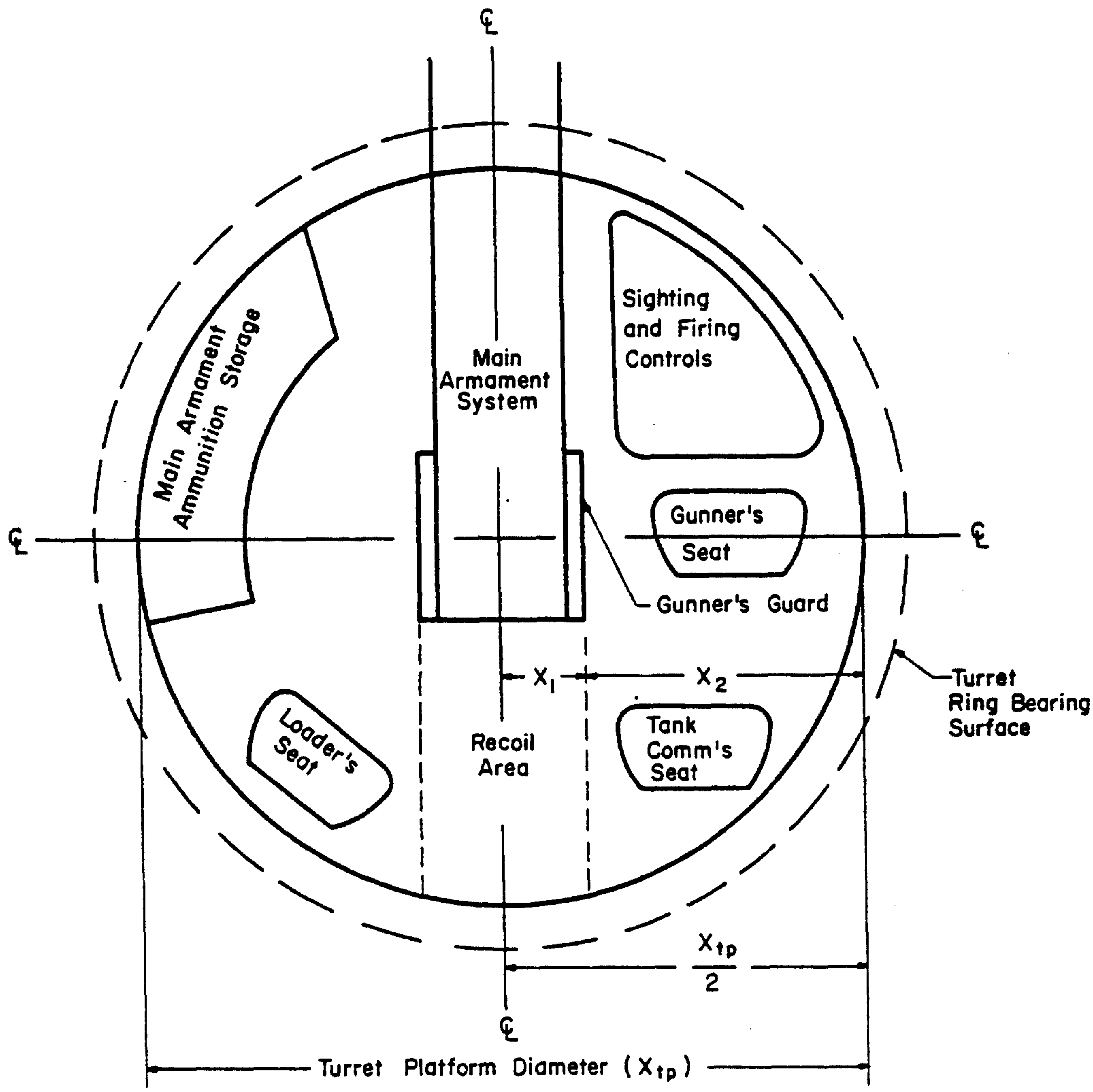
As shown in Figure 66, the turret fighting compartment of a conventional tank is characterized by the following features: 1) the gunner's seat is located to the right of the main armament (MA) system on the transverse center line (C_L) of the compartment, 2) the tank commander's seat is located immediately behind that of the gunner, and 3) the MA loader is stationed to the rear of the left-hand side of the turret fighting compartment as it is viewed from the top.

As indicated by Figure 66, the turret platform width X_{tp} can be broken down into

$$X_{tp} = 2(X_1 + X_2) , \qquad (2)$$

where X_2 includes the clearance between the gunner's guard and his seat, the gunner's seat width, and the clearance between his seat and the outside edge of the turret platform.

The magnitude of the X_1 dimension is dependent on the bore diameter of the MA system, the maximum internal pressure, and the thickness of the gunner's guard shield. For a given design state-of-the-art, a fixed gunner's



Plan View of Turret Fighting Compartment for a Conventional Tank Design

Figure 66

guard shield thickness, and a given maximum internal pressure, the required magnitude of X_1 increases with increasing bore diameter. The magnitude of the X_2 dimension depends upon such factors as crew comfort, safety requirements, and required accessibility of equipment.

Values of X_1, X_2, and X_{tp} for several conventional tanks are given in Table 18. We note that X_1 increases with increasing bore size for the M41A1 (76 mm), M48 (90 mm) and M60 (105 mm) tanks. The M551 vehicle with a 152 mm bore "Shillelagh" main armament system exhibits a smaller X_1 value than the above three vehicles. In this respect the "Shillelagh" could be considered to be an improvement in the main armament system design state-of-the-art over the main armament systems for the older M41A1, M48, and M60 tanks. Consequently, any use of these data for determining a representative value for

Table 18

Observed Values of X_1, X_2, and X_{tp} for Four Conventional Tanks[a]

Tank Nomenclature	X_1	X_2	X_{tp}
M551 (152 mm gun)	9.0"	22.0"	62"
M60 (105 mm gun)	11.5"	29.5"	82"
M48 (90 mm gun)	10.0"	31.0"	82"
M41A1 (76 mm gun)	9.5"	24.0"	67"

[a]The "observed" values of X_1, X_2, and X_{tp} presented are as measured from ATAC Class and Division drawings.

the X_1 dimension must consider not only bore size but also the design state-of-the-art with respect to maximum internal pressure and gunner's guard shield thickness. Thus, when predicting the size of the main armament system for a proposed vehicle it is best to have a specific type of main armament system in mind.

The observed values of X_2 in Table 18 do not necessarily represent limiting values for each of these vehicles since the width of the power train system may have determined the hull width. Consequently, the minimum observed value of X_2 (22 inches for the M551 vehicle) is the best estimate (from past tank designs) of the theoretical minimum (limiting) value for this dimension.

Power Train System Width

The volume within the hull attributable to the power train system is comprised of the engine, the transmission, the final drive units, the fuel system (including tanks, pumps, lines, etc.), the accessories attached to the engine and transmission, and the clearance space around the power train. This latter space is required for maintenance accessibility and for cooling purposes. The dimensions related to power train size and placement which comprise the hull width are shown in Figure 67.[1] In Figure 67, X_5 denotes the engine overall width, X_6 denotes the clearance between the engine and the hull side walls,

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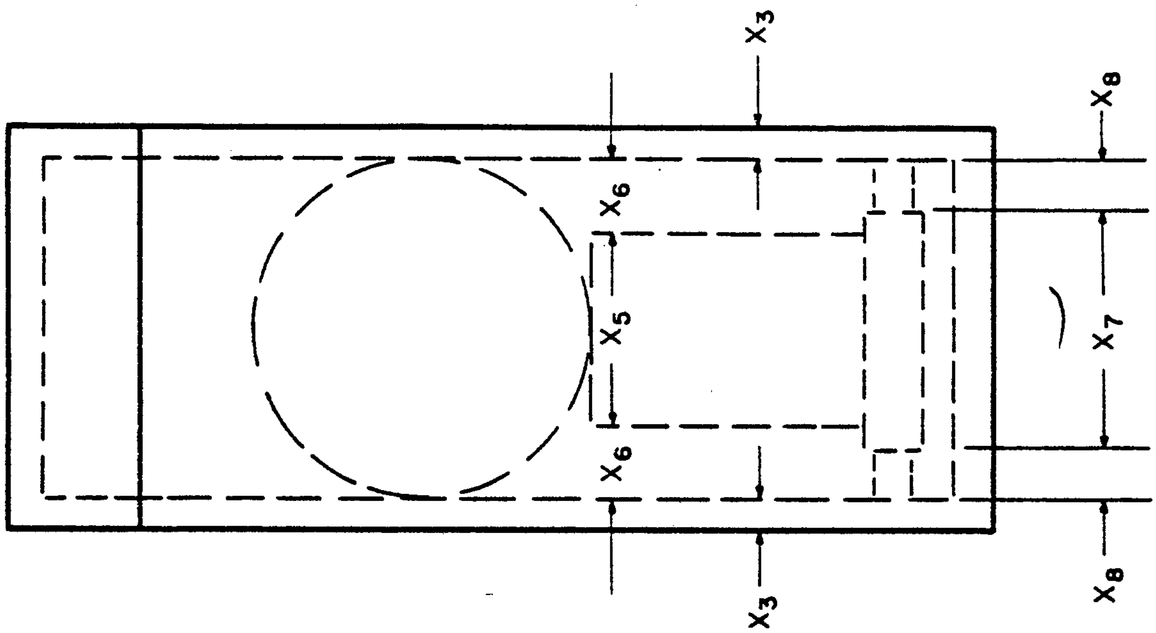
[1]The power train is assumed to be centered laterally in the hull for conventional tanks as shown in Figure 65.



Top View of a Conventional Tank Showing
Power Train Component Dimensions

Figure 67

X_7 denotes the overall width of the transmission, and X_8 denotes the width of each of the final drive units.[1] Thus, with respect to the power train size (i. e., disregarding the turret fighting compartment size), the limiting inside hull width X_{Hpt} can be expressed as

$$X_{Hpt} = \max \left[(X_5 + 2X_6), \ (X_7 + 2X_8) \right] , \qquad (3)$$

where X_6 is the specified minimum allowable horizontal distance between the engine and the hull side walls.

---

[1] In conventional tanks, a final drive unit is either attached to each end of the transmission or the final drive may be an integral part of the transmission. The transmission and final drive assembly may butt up to the side walls of the hull. For those power train systems for which the final drive is an integral part of the transmission assembly (e. g., the XTG-250-1A transmission for the M551 vehicle), $X_8 = 0$ and X_7 equals the overall width of the transmission assembly.

Power train system component dimensional data for the M551, M60, M48, and M41A1 tanks are presented in Table 19. The four vehicles in Table 19 do not all employ the same types of power train systems. The M551, M60, and M48 each employ "V" configuration, air-cooled, diesel engines while the M41A1 employs a horizontally "opposed" 6 cylinder spark-ignition gasoline engine. Furthermore, the M551 vehicle design possesses an XT series transmission (with integral final drive) while the other three vehicles possess cross-drive (CD) series transmissions (with separate final drives).[1] Obviously, any use of these data for determining representative empirical equations for estimating X_5 and X_7 values must be made with consideration to the component type (gasoline, diesel, turbine, etc., for the engine; CD series, XT series, electric drive, etc., for the transmission).

For a given type engine, engine width X_5 should be related to engine gross horsepower (GHP). In like manner, for given types of transmissions and final drive units, the widths X_7 and X_8 should depend on the GHP of the engine. The data given in Table 19 were used to get the following linear "least squares" equations for "V" configuration air-cooled diesel engines and CD

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[1]The cross-drive transmission is composed of a hydraulic torque converter, an epicyclic gear train giving two speeds forward and one in reverse, and hydraulically controlled planetary gear sets for steering. The XT series represents an improvement in the track-laying vehicle transmission design state-of-the-art. It is composed of a single-stage polyphase torque converter, a lockup clutch, and a reverse planetary transmission providing three speeds forward and one reverse. This transmission has considerably fewer components than the CD series transmission and can be produced at lower cost (AMCP 706-355, 1965).

Table 19[a]

Observed Values of X_5, X_6, X_7, and X_8 for Four Conventional Tanks

Tank Nomen-clature	X_5	X_6	X_7	X_8	Engine Designation, Type, & GHP	Transmission Designation
M551	36.6"	12.7"	46.0"	0	6V53T, V-6 diesel, 300 GHP	XTG-250-1A
M60	56.6"	12.7"	53.5"	23.3"	AVDS-1790-2 V-12 diesel, 750 GHP	CD-850-6
M48	58.8"	11.6"	53.5"	23.3"	AVDS-1790-7B V-12 diesel, 810 GHP	CD-850-4
M41A1	51.5"	7.75"	44.7"	26.0"	ADS-895-3 OPP. -6 gas, 500 GHP	CD-500-3

[a]The dimensions and component designations given in this table were provided by the ATAC Propulsion Systems Laboratory.

series transmissions[1] in terms of the gross horsepower G_{HP}:

$$\bar{X}_5 = .0438\ G_{HP} + 23.6,\ \text{inches} \tag{4}$$

and

$$\bar{X}_7 = .0284\ G_{HP} + 30.5,\ \text{inches} \tag{5}$$

---

[1]In order to predict the dimensions of other types of components (e.g., a "V" configuration spark ignition gasoline engine) representative data must be acquired from the component manufacturer.

where $\overline{X}_5$ and $\overline{X}_7$ are linear "least squares" predictions of X_5 and X_7. Since modifications of the CD-850 transmission were employed in both the M48 and M60 vehicles, it is not valid to treat each as separate data points in a least squares fit. Thus, the above equation for $\overline{X}_7$ is the expression of the line between the points for the M41A1 and the M48 transmissions. The equation for $\overline{X}_5$ is based upon the three data points for the M48, M60, and M551 vehicles. These equations are presented to illustrate methodology only; it is not recommended that they be used to predict the dimensions of future power train components since they are based upon so few data points.

Additional data should be obtained from engine and transmission manufacturers so that a meaningful least squares relationship can be derived. However, it should be noted that, if one has a particular power train system in mind, a manufacturer's estimate of these dimensions would be superior to estimates based on past data. This is particularly the case since the data used to form the "least squares" equations may be biased by factors not previously considered in our analysis. One factor might be that the sizes of these components may have been heavily influenced by the employment of "in stock" subcomponents or that there might have been a lack of concern for reducing the size of the power train system for some vehicle designs. A "lack of concern" might have occurred in cases where the minimum allowable width of the vehicle was already determined by turret platform limitations.

The danger in using two or three data points for the purpose of predicting the dimensions of future components can be exhibited by the X_8 dimensional

data of Table 19 which seem to contradict our assumption that X_8 increases with GHP. Of the three vehicles of Table 19 employing separate final drive units, the M41A1 exhibits the least engine horsepower, yet it has the greatest X_8 dimension.

Although X_6 must be large enough to provide maintenance areas, fuel-tank volume, and air-cooling space for the engine, this dimension may also include slack (waste space) especially in cases where the hull width was determined by turret platform or transmission assembly width. Consequently, it is impossible to determine the degree to which the values of X_6 in Table 19 represent limiting values for this dimension. The minimum observed value for X_6 (i.e., 7.75" for the M41A1 vehicle) is the best available estimate (based on past tank data) of the theoretical minimum value for this dimension.

Hull Width

Since the inside hull width (the width of the usable volume within the hull) X_H is determined by either the limiting turret platform diameter or the limiting power train system width,

$$X_H = \max \left[X_{tp}, X_{Hpt} \right], \tag{6}$$

where X_{tp} is defined by equation 2 and $X_{H_{pt}}$ is defined by equation 3. From equations 2 and 3, we see that

$$X_H = \max \left[2(X_1 + X_2), (X_5 + 2X_6), (X_7 + 2X_8) \right] \tag{7}$$

and from equation 1, that

$$X_0 = \max\left[2(X_1 + X_2), (X_5 + 2X_6), (X_7 + 2X_8)\right] + 2X_3 + 2X_4. \qquad (8)$$

The hull side-armor thickness X_3 depends upon the degree of protection desired. Thus, this dimension should be determined on the basis of an analysis of such factors as the expected enemy threat, the type of material used and its vulnerability to that threat, and the tactical needs of the proposed vehicle, i.e.; the tactical needs theoretically should dictate the trade-off between mobility and protection which are both dependent on armor weight. Such a trade-off analysis is beyond the scope of this paper.

The limiting track width X_4 is discussed later in this report. In the following section we discuss a methodology for estimating the hull length and track-ground contact length.

Hull and Track-Ground Contact Lengths

The applicability of component dimensions (from past designs) for estimating future tank dimensions depends on the degree to which these dimensions were minimized in an effort to reduce the overall hull length of each respective design. As previously noted (see footnote on page 289), the relative amount of R & D effort expended to reduce the size of respective components is not known. Therefore, in a strict sense, it is impossible to determine the degree to which these component dimensions represented the state-of-the-art at the time each tank was designed. However, if the components are nonoverlapping,

as in the case of vehicle hull length, it may be safe to assume that a reasonable amount of effort was expended on each component.[1] This assumption would not apply as well in the case of vehicle width (previously discussed) where, because of overlapping, the hull width is determined by either the turret platform diameter, the engine width, or the transmission system width. That is, R & D effort to minimize (or reduce) tank width probably would have been expended on either the engine or the transmission, for example, if either of the respective widths exceeded that of the turret platform diameter.

An estimate of the internal hull length is needed in order to estimate the gross vehicle weight and the track-ground contact length.[2] In the remainder of this section we discuss the estimation of overall hull-length and track-ground contact length.

Overall Hull Length

With reference to Figure 68 of this section, the overall hull length Y_0 for a conventional tank is given by

$$Y_0 = Y_H + Y_1 + Y_9 , \qquad (9)$$

where

$$Y_H = \sum_{i=2}^{8} Y_i \qquad (10)$$

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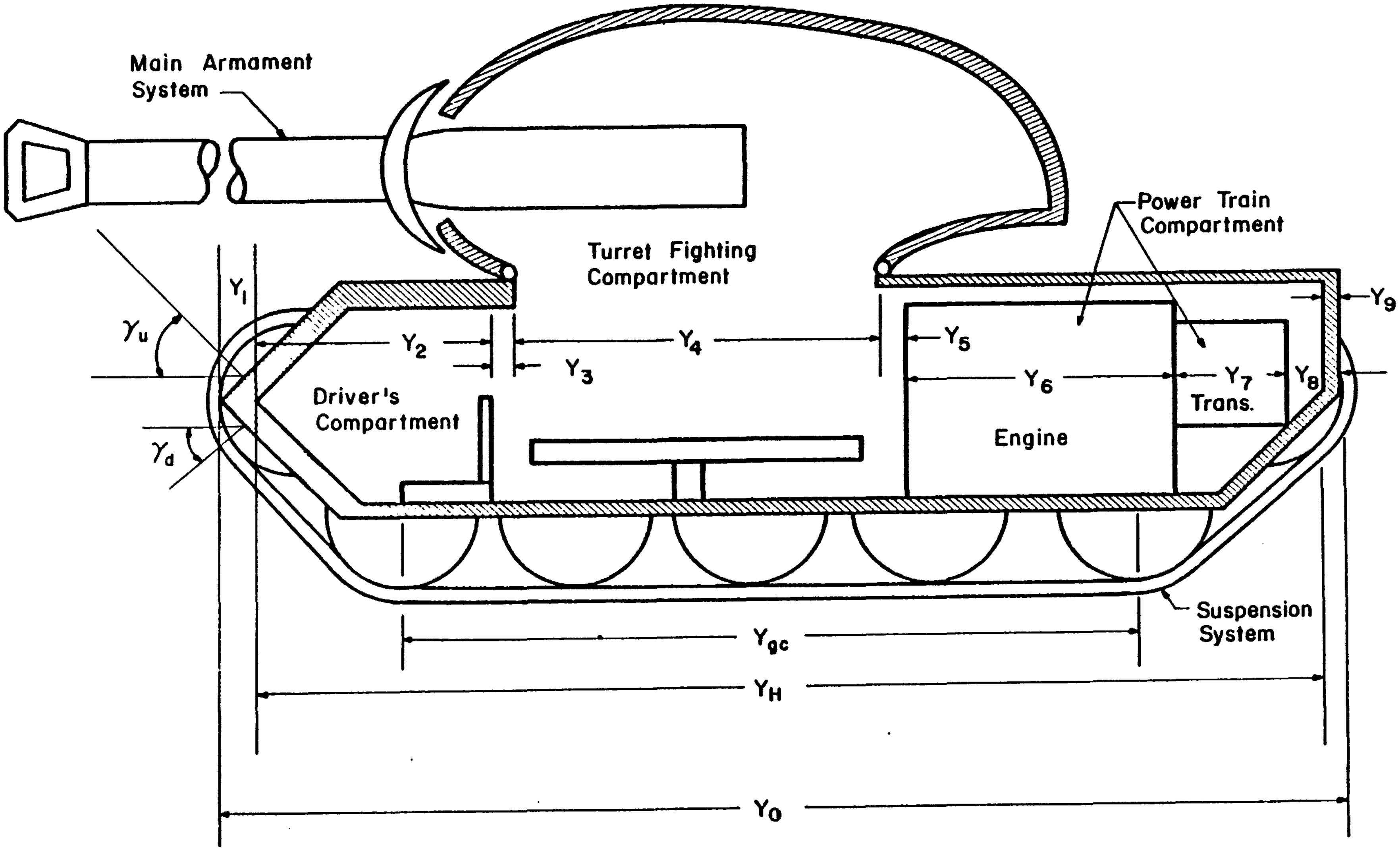
[1]This assumption should be considered in light of information concerning the use of "stock" items in each tank design.

[2]Gross vehicle weight estimation is discussed later in this report.



Sectional Elevation View of a Conventional Tank Showing a Breakdown of the Hull Length

Figure 68

and

Y_H = the internal hull length,

Y_1 = the horizontal thickness of the armor at the front edge of the hull,

Y_2 = the horizontal distance from the point on the inside hull defining Y_1 to the rear edge of the driver's seat,

Y_3 = the horizontal distance from the rear edge of the driver's seat to the turret ring ball race center line. (By convention, the positive sense is from the front to the back of the hull.),

Y_4 = the turret ring ball race diameter,

Y_5 = the horizontal distance from the turret ball race center line to the front edge of the engine (or power plant),[1]

Y_6 = the engine (or power plant length),

Y_7 = the transmission length,

Y_8 = the horizontal clearance between the transmission and the rear hull, and

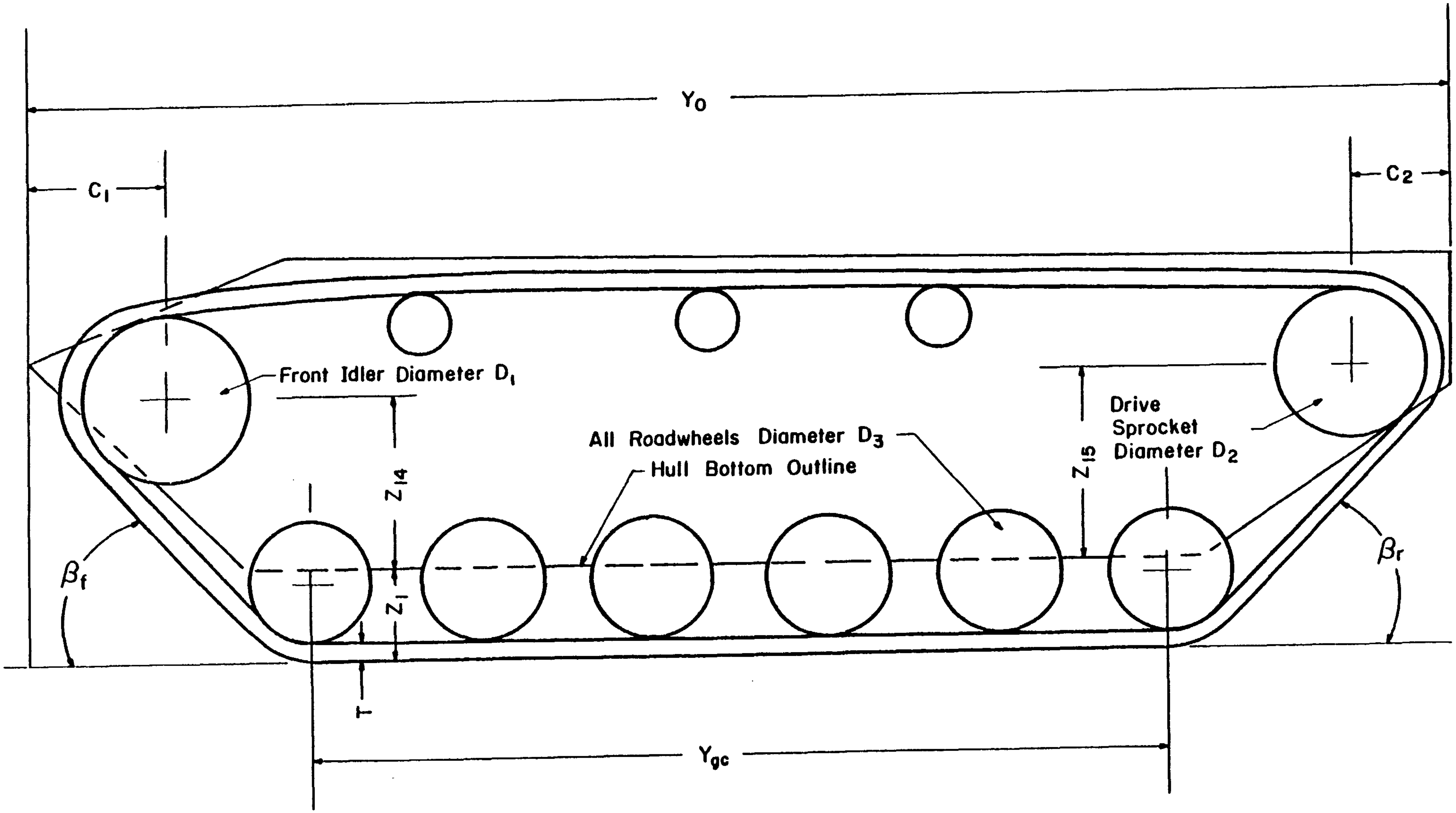
Y_9 = the hull upper back armor thickness.

Relationship Between Hull Length and Track-Ground Contact Length

The track-ground contact length Y_{gc} is primarily determined by the overall hull length Y_0. However, many other critical dimensions must be considered.

A profile view of the conventional tank suspension system is shown in Figure 69. The relationship between the ground contact length Y_{gc}, the hull

[1]For the sake of generality this dimension is included here; however, for the four vehicle designs considered in this discussion Y_5 was observed to be essentially zero.



Sketch Showing the Spatial Relationship between Hull Length (Y_0) and Ground Contact Length (Y_{gc})

Figure 69

length Y_0, and component dimensions shown in Figure 69 , is

$$Y_{gc} = Y_0 - \left[C_1 + C_2 + \frac{2\cos\beta_f\left[Z_{14} + Z_1 - \left(T + \frac{D_3}{2}\right)\right] - (D_1 - D_3)}{2\sin\beta_f} + \frac{2\cos\beta_r\left[Z_{15} + Z_1 - \left(T + \frac{D_3}{2}\right)\right] - (D_2 - D_3)}{2\sin\beta_r}\right], \quad (11)$$

where:

C_1 = the horizontal distance from the front outside edge of the hull to center of the track idler,

C_2 = the horizontal distance from the drive sprocket center to the rear outside edge of the hull,

β_f = the lead (approach) angle of the tracks,

β_r = the trail (departure) angle of the tracks,

Z_{14} = the vertical height of the idler center above the hull bottom,

Z_{15} = the vertical height of the drive sprocket center above the hull bottom,

Z_1 = the hull ground level clearance,

T = the track thickness,

D_1 = the track front idler diameter,

D_2 = the drive sprocket diameter, and

D_3 = the diameter of the road wheels.

Methods of estimating the independent variables in equations 9, 10, and 11, using values from past tank designs (to the extent that they can be considered

representative of future conventional-type tanks--see footnote on page 289) are discussed in the following section.

Estimation of Hull Length Component Dimensions

The observed values of $Y_1, \cdots, Y_9$ for four conventional tanks are given in Table 20. Various factors, which might have influenced these data or which might influence the values of $Y_1, \cdots, Y_9$ in future tanks, are discussed below.

The horizontal thickness of the frontal armor at the front edge of the hull Y_1 is determined from the angles of slope of the upper and lower portions of the front hull armor and their true (normal) thicknesses; that is,

$$Y_1 = \frac{t_{hfu}}{\cos \gamma_u} = \frac{t_{hfl}}{\cos \gamma_d}, \qquad (12)$$

where:

t_{hfu} = the true (normal) front upper hull armor thickness,

t_{hfl} = the true (normal) front lower hull armor thickness,

γ_u = the obliquity of the front upper hull armor, and

γ_d = the obliquity of the front lower hull armor.

The values of the driver's compartment length Y_2 in Table 20 appear to be fairly constant. The average value of Y_2 (i.e., $\overline{Y}_2 = 56.5$ inches) for the four tanks of Table 20 is the best available estimate from past data of this dimension.[1]

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[1]An "average" value is suggested here (and in other instances in this chapter) instead of a least squares equation since there is no scalable independent variable upon which to base a least squares equation.

Table 20[1]

Observed Values of $Y_1, \cdots, Y_9$ for Four Conventional Tanks

Tank Nomenclature	Y_1	Y_2	Y_3	Y_4	Y_5 ¶	Y_6	Y_7	Y_8	Y_9	Engine Designation Type, & GHP	Transmission Designation
M551	*	58"	11.0"	77"	0	44.9"	30.6"	12.0"	*	6V53T, V-6 diesel, 300 GHP	XTG-250-1A
M60	11"	57"	1.0"	85"	0	66.5"	29.0"	17.0"	1.5"	AVDS-1790-2 V-12 diesel, 750 GHP	CD-850-6
M48	7"	57"	-1.25"	85"	0	68.0"	29.0"	18.5"	1.5"	AVDS-1790-7B V-12 diesel, 810 GHP	CD-850-4
M41A1	1.5"	54"	-1.0"	76"	0	45.4"	34.2"	7.0"	0.8"	ADS-895-3 OPP. -6 gas, 500 GHP	CD-500-3

*Classified Information

[1] The dimensional data in this table was measured from the appropriate ATAC "Class and Division" drawings.

¶ See footnote on page 302.

The observed values of Y_3 in Table 20 indicate a large variability from design to design. In conventional tanks, the volumes to each side of the driver are occupied by main armament ammunition storage. The large value of Y_3 for the M551 may have resulted from the fact that this tank is required to handle rounds which are 6" longer than those carried by the other tanks listed in Table 20.[1] Consequently, the average, $\overline{Y}_3 = -.083$ inches, computed for the remaining three tanks, may be more representative of conventional tank design than the value observed for the M551 vehicle. Negative values of Y_3, such as those exhibited by the M48 and the M41A1 vehicles, can occur since the back edge of the driver's seat can extend to the edge of the turret platform which is within the confines of the turret-ring bearing circle. In conventional tanks, the turret ring diameter is made larger than the turret platform so that the turret assembly (including the platform or floor) can be pulled from the hull.

In order to estimate the turret ring diameter Y_4, we assume that

$$Y_4 = X_{tp} + K_1 , \qquad (13)$$

where:

X_{tp} = the turret platform diameter, and

K_1 = the clearance between the turret platform and the turret ring.[2]

---

[1]The lengths of the longest type round for each of the four conventional tanks are given under the heading Y_{21} in Table 22 of the Overall Vehicle Height section. The hull-length estimation methodology presented in this paper does not consider ammunition length in estimating Y_3.

[2]The turret platform diameter X_{tp} is determined by space requirements of the main armament system and the crew; however, depending upon the design objective for the vehicle, the turret ring diameter may fall anywhere in the range $X_{tp} < Y_4 < X_0$.

Values for K_1 from past tanks are 15 inches for the M551, 3 inches for the M60, 3 inches for the M48, and 9 inches for the M41A1. The average of these K_1 values is 7.5 inches.

For a given type of engine or transmission, the engine length Y_6 and the transmission length Y_7 should be related to GHP. That is, we would expect both Y_6 and Y_7 to increase with increasing GHP. The linear "least squares" equation

$$\overline{Y}_6 = .0463 \ G_{HP} + 31.09, \tag{14}$$

was derived using the length data (Table 20) for the three "V" configuration, air-cooled, diesel engines. The prediction of Y_6 given by equation 14 is in inches. This linear "least squares" equation is based on only three data points. Its validity could be improved by including data points from additional engines. Such data could be acquired from various engine manufacturers. However, as previously noted, if one has a particular power train system in mind, a manufacturer's estimate of these dimensions would be superior to estimates based on an equation such as (14).

The M60, M48, and M41A1 vehicles all employ CD series transmissions. However, considering these three vehicles, the Y_7 dimensions is greatest for the M41A1 vehicle whose engine GHP is smallest (see Table 20). Thus, the data of Table 20 seem to contradict the hypothesis that Y_7 increases with GHP. This contradiction may be due to the fact that the M60 and M48 vehicles employ newer transmissions which are more representative of the current design

state-of-the-art. Thus, the values of Y_7 for the M60 and M48 vehicles may be more representative of a conventional tank of the future which has a GHP within the range 750 to 810 GHP (than the M41A1 transmission-length value).

The horizontal clearance Y_8 between the transmission and the rear hull wall is necessary for ease of maintenance of the power train system and/or for air flow purposes. The average $\bar{Y}_8 = 13.6$ inches could be used to estimate this dimension. The hull upper back armor thickness Y_9 and the true (normal) front upper hull armor thickness t_{hfu} are design parameters which depend upon the degree of protection desired and the structural requirements of the proposed vehicle. No estimates of these armor thicknesses are given since such estimates must be based upon enemy threat and lethality considerations.

The hull front-edge armor thickness Y_1 is related to t_{hfu} and the obliquity γ_u by equation 12. The obliquity γ_u of the upper front hull increases resistance to projectile penetration by presenting a greater thickness of armor to the path of the projectile and by deflecting the projectile. The observed upper front hull armor obliquity for the M551 is 83^o, for the M60 is 64^o, for the M48 is 58^o, and for the M41A1 is 59^o. If we disregard the M551 vehicle, which has ballistic aluminum armor, since it appears to possess an exceptionally high γ_u value, then the variability in γ_u for the remaining three vehicles is relatively small. For a conventional tank with steel armor, the average $\bar{\gamma}_u = 60^o$ for these three vehicles could be used to estimate γ_u.

Track Ground Contact Length Parameters

Values of the track-ground contact length parameters of equation 11 (see Figure 69) for the four conventional tanks are presented in Table 21. The track thickness T, the track lead and trail angles β_f and β_r, the hull ground clearance Z_1, and the diameters of the idler, sprocket, and road wheels (D_1, D_2, and D_3) are usually determined from considerations such as required mobility performance other than that of overall length. On the other hand, the distances Z_{14}, Z_{15}, C_1, and C_2 may be affected by overall length restrictions. Approximations of C_1 and C_2 are given by

$$C_1 = \frac{D_1}{2} + T$$

and

$$C_2 = \frac{D_2}{2} + T,$$

where T is the track thickness.

Since neither the idler and the front road wheel nor the rear road wheel and the sprocket can interfere with each other, Z_{14} and Z_{15} must satisfy the following inequalities (see Figure 69):

$$Z_{14} \geq \left[\sqrt{\left(\frac{D_1 + D_3}{2}\right)^2 - \left(\frac{D_1 - D_3}{2}\right)^2} + \frac{D_1 - D_3}{2 \tan \beta_f} \right] \sin \beta_f + T + \frac{D_3}{2} - Z_1 \qquad (15)$$

and

Table 21[a]

Observed Track-Ground Contact Length Parameters

Tank Nomenclature	C_1	C_2	β_f	β_r	Z_{14}	Z_{15}	Z_1	T	D_1	D_2	D_3	Y_{gc}
M551	7.75"	25"	31.0°	29.0°	11.5"	9.5"	19.0"	2.3"	15.5"	16.73"	28.0"	140.0"
M60	22.0"	11"	34.75°	44.5°	20.5"	24.0"	18.25"	4.5"	26.0"	24.5"	26.0"	166.72"
M48	19.0"	22"	36.0°	39.0°	19.0"	24.8"	18.0"	4.5"	26.0"	24.5"	26.0"	157.5"
M41A1	15.0"	19"	31.0°	33.0°	12.8"	14.0"	17.75"	3.7"	22.5"	23.4"	25.5"	127.0"

[a]The data of this table was measured from the appropriate ATAC "Class and Division" drawings.

$$Z_{15} \geq \left[\sqrt{\left(\frac{D_2+D_3}{2}\right)^2-\left(\frac{D_2-D_3}{2}\right)^2}+\frac{D_2-D_3}{2\tan\beta_r}\right]\sin\beta_r+T+\frac{D_3}{2}-Z_1. \qquad (16)$$

No procedure is given for the estimation of D_1, D_2, and D_3. The drive sprocket diameter D_2 is determined by gear reduction and space limitation requirements. Generally, the idler wheel and road wheel diameters are selected to be compatible with the limited space available for the suspension. Bogie-type suspensions generally employ rather small-diameter road wheels, while independently suspended road wheels are usually more than 18 inches in diameter (AMCP 706-355, 1965).

In the following section a methodology for estimating the overall height of a conventional tank is discussed.

Overall Vehicle Height

The overall vehicle height refers to the height of the vehicle from ground level to the top of the turret (less the tank commander's cupola).[1] This height is the sum of three factors; 1) the heights (above ground) of the hull front or rear deck (whichever is larger), 2) the necessary vertical height of the MA trunnion center line above the front and rear decks necessary for rotation of the turret with MA tube maximally depressed, and 3) the distance

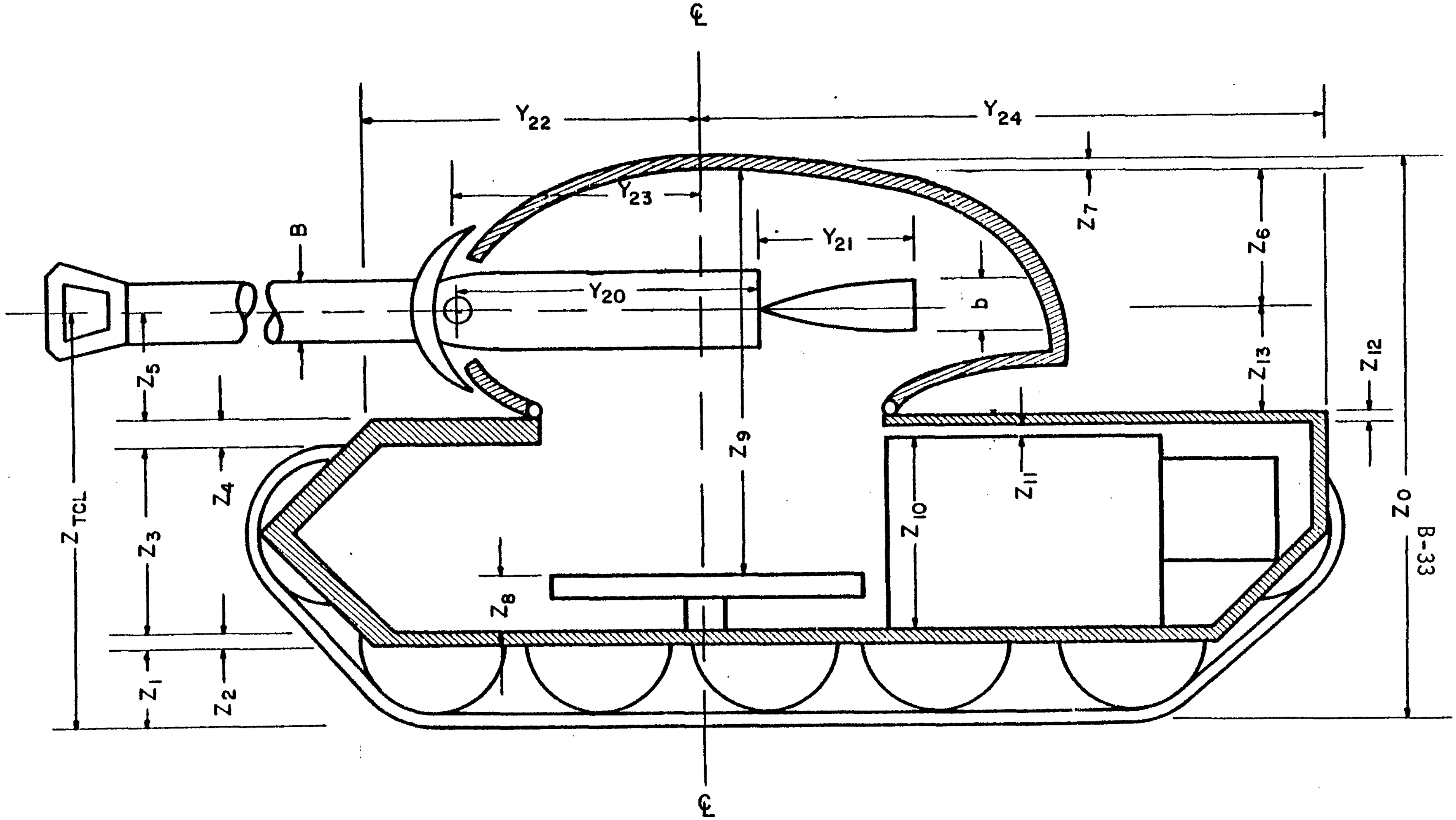
[1]Since there was no observable relationship between the height of the tank commander's cupola above the turret and any scalable independent variable, the overall height of the vehicle (with cupola) can be predicted using this methodology only if the height of the cupola is known or can be estimated by some other means.

from the trunnion center line to the top of the turret. These dimensions are exhibited in Figure 70.

The hull front-deck height must accommodate the vehicle driver whereas the rear-deck height must be consistent with power train dimensions. Both dimensions must provide for hull-ground clearance and include armor thicknesses for the hull bottom and top. The main-armament trunnion center line must be located above the hull at such a height that the MA tube will not interfere with the hull (front or rear deck) as it traverses (the hull) at its maximum depression angle. The distance from the trunnion center line to the inside of the turret roof should allow the longest length round to be loaded into the MA system with the tube at its maximum depression angle. In addition, it may be required that the turret roof be sufficiently high to allow the crew to stand upright. In this case, the sum of the three factors noted above should be compared with the vehicle height estimated using expected crew height, and the maximum of these two estimates should be taken as the limiting overall vehicle height.

The Required Heights of the Hull Front and Rear Decks

The required height of the hull front deck above ground level (see Figure 70) is equal to the sum of ground clearance Z_1, the hull bottom armor thickness Z_2, the vertical distance Z_3 from the inside of the hull floor to the inside of the front hull ceiling above the driver's head necessary to accommodate the tank driver, and the hull-front deck armor thickness Z_4.



Sectional Elevation View of a Conventional Tank Showing Vehicle Height Dimensions and Associated Vehicle Height Estimation Parameters

Figure 70

The required height of the hull rear deck above ground level is the sum of Z_1, Z_2, the vertical overall height Z_{10} of the engine or power plant including accessories, the clearance Z_{11} between the engine and the hull rear deck; and the hull rear deck armor thickness Z_{12}.

The Required Height of the Trunnion Center Line above Ground Level

The methodology contained in this section is primarily concerned with predicting the height of the trunnion center line (above ground level), considering the restrictions arising from required depression angles and hull heights in both the front and the rear of the vehicle.

With reference to Figure 70, the height of the trunnion center line, Z_{TCL}, for a conventional tank must be such that the two inequalities

$$Z_{TCL} \geq Z_1 + Z_2 + Z_3 + Z_4 + Z_5 \tag{17}$$

and

$$Z_{TCL} \geq Z_1 + Z_2 + Z_{10} + Z_{11} + Z_{12} + Z_{13} \tag{18}$$

are satisfied. Thus, we take Z_{TCL} as

$$Z_{TCL} = Z_1 + Z_2 + \max\left[(Z_3 + Z_4 + Z_5), (Z_{10} + Z_{11} + Z_{12} + Z_{13})\right], \tag{19}$$

where:

Z_1 = the hull ground clearance,

Z_2 = the hull bottom armor thickness,

Z_3 = the vertical distance from the inside of the hull floor to the inside of the front hull ceiling above the driver's head,

Z_4 = the vertical distance between the ceiling directly above the vehicle driver's head and the point on the vehicle's front upper hull which comes closest to interfering with the depressed main armament tube as it rotates (with the turret) over the front hull, (In the absence of other information this dimension will be assumed to equal the thickness of the hull front-deck armor.)

Z_5 = the vertical distance from the point on the front upper hull defining the Z_4 dimension to the main armament trunnion center line,

Z_{10} = the vertical overall height of the engine or power plant including accessories,

Z_{11} = the clearance between the engine and the rear deck of the hull,

Z_{12} = the vertical distance between the ceiling directly above the engine (or power plant) and the point on the hull rear deck which comes closest to interfering with the main armament tube as it rotates over the hull rear deck about the turret rotational axis, and

Z_{13} = the vertical distance from the point on the hull rear deck defining the Z_{12} dimension to the main armament trunnion center line.

The Required Height of the Turret Roof above the Trunnion Center Line

The required distance Z_6 between the turret roof and the trunnion center line can be determined assuming that it will allow the longest type of MA round to be lined up with the breech parallel to the MA tube without hitting the turret roof when the tube is at the maximum depression angle.[1] Thus, in

[1] Admittedly, this requirement, i.e., that the main armament round must line up parallel to the breech for loading, is not strictly adherred to since the breech ring is slotted on the side to facilitate loading and since the front end of the round is normally tapered. For this reason the Z_6 values determined from (20) should be considered to be upper limits of this dimension.

accordance with Figure 70,

$$Z_6 = (Y_{20} + Y_{21}) \sin \alpha_f + \frac{b}{2 \cos \alpha_f} , \qquad (20)$$

where:

Z_6 = the vertical distance from the main armament trunnion center line to the turret ceiling at the side-to-side center of the turret in the area above the breech,

Y_{20} = the horizontal distance from the trunnion center line to the rear face of the breech of the main armament system,

Y_{21} = the length of longest type of round fired (or launched) by the main armament system,

α_f = the desired maximum depression angle of the main armament tube over the front hull, and

b = the MA system bore diameter.

In equation 20, we have assumed that α_f is not less than the desired maximum depression angle of the main armament tube over the rear hull.

If we let Z_7 represent the turret roof armor thickness then the overall vehicle height Z_0 can be predicted as

$$Z_0 \geq Z_{TCL} + Z_6 + Z_7. \qquad (21)$$

Equation 21 does not consider a requirement for the crew (especially the MA loader) to have sufficient space to stand within the turret fighting compartment. If such a requirement exists for a future design, then Z_0 must also satisfy the inequality

$$Z_0 \geq Z_1 + Z_2 + Z_8 + Z_9 + Z_7 , \qquad (22)$$

where:

Z_7 = the turret roof (armor) thickness in the area above the breech,

Z_8 = the vertical height from the inside of the hull bottom to the top of the turret platform in the area below the breech, and

Z_9 = the vertical distance from the turret platform floor level to the inside roof of the turret (in the area about the breech) necessary to accommodate the crew.

If we take Z_0 to be the minimum value which satisfies (21) and (22), then

$$Z_0 = Z_1 + Z_2 + \max\left[\left(Z_3 + Z_4 + Z_5 + Z_6\right), \left(Z_{10} + Z_{11} + Z_{12} + Z_{13} + Z_6\right), \left(Z_8 + Z_9\right)\right] + Z_7 . \qquad (23)$$

In the following section, estimation of the dimensions $Z_1, Z_2, \cdots, Z_{13}$ using data from the four conventional type tanks, the M551, M60, M48, and M41A1 vehicles, is discussed.

Prediction of Overall Vehicle Height Component Parameters

The observed values of the height parameters of Figure 70 for the four conventional tanks are shown in Table 22. The applicability of these data to predicting values of Z_1 through Z_{13} for future conventional type tanks is discussed in the following paragraphs.

The height of a tank vehicle is greatly affected by the ground clearance Z_1 specified in the military characteristics. "Currently, the minimum ground clearance is 17 inches with values up to 20 5/8 inches being attained," (AMCP

706-355, 1965) for tracked vehicles. This variable should be determined on a basis of mobility requirements. In the absence of a mobility analysis, any value between 17 and 20 5/8 inches would appear to be a safe estimate.

The hull bottom armor thickness Z_2 depends upon the degree of protection desired and the expected threat to this area of the vehicle. This variable should be determined on a basis of desired protection characteristics. All values given in Table 22 appear equally as representative.

The observed values in Table 22 of the front hull internal height Z_3 do not necessarily represent limiting values for each of these vehicles since Z_{TCL} (see equation 19) may have been determined by the sum of Z_{10}, Z_{11}, Z_{12}, and Z_{13} (i.e., the rear hull geometry) and not by the front hull geometry. The height of the power train (Z_{10} and Z_{11}) may have been such that the trunnion center line height Z_{TCL} was determined by the rear deck height. In this case a reduction of the height of the front hull deck would not result in a reduction in the overall height of the vehicle. Consequently, the minimum observed value of Z_3 (38 inches for the M41A1 vehicle which has a low profile engine) is the best available estimate of the limiting value of this dimension.

The front hull deck armor thickness Z_4 should be determined considering the expected enemy threat and the degree of protection desired as in the case of Z_2 above. The vertical distance Z_5 from the point on the front upper hull defining the Z_4 dimension to the MA trunnion center line must be such that the main armament tube will clear all points on the front hull and the tracks as it (the tube) rotates at angle α_f over the front hull. If we assume

Table 22[a]

Component Overall Height Dimensions

Tank Nomenclature	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8	Z_9	Z_{10}	Z_{11}	Z_{12}	Z_{13}	B	Y_{20}	Y_{21}	Y_{22}	Y_{23}	Y_{24}	b	α_f	α_r	$\frac{X_0}{2}$
M551	19.0"	1.5"	43.0"	**	12.0"	13.0"	1.0"	7.5"	61.5"	38.8"	1.2"	1.0"	14.5"	11.0"	36.0"	43.7"	62"	38.0"	102"	6.1"	8.0°	8.0°	55.0"
M60	19.5"	0.75"	42.5"	3.0"	16.0"	20.5"	1.25"	16.25"	67.5"	44.2"	11.8"	1.0"	5.0"	5.0"	50.5"	36.8"	75"	42.5"	--	4.14"	9.0°	0.0°	71.5"
M48	18.0"	1.0"	41.5"	3.0"	13.5"	21.5"	1.25"	14.5"	67.2"	39.8"	15.2"	1.0"	5.5"	4.0"	49.5"	37.6"	76"	42.5"	--	3.54"	9.0°	0.0°	71.5"
M41A1	18.0"	0.5"	38.0"	2.5"	13.25"	17.75"	0.75"	9.5"	64.5"	34.2"	7.7"	0.75"	11.75"	4.0"	50.5"	33.8"	83"*	36.0"	85"	3.0"	9.75°	9.75°	63.0"

*To front edge of headlight guard
**Confidential Information

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[a]The dimensional data in this table were measured from the appropriate ATAC "Class and Division" drawings.

that the fenders over the tracks follow the contour of the hull, the Z_5 dimension can approach a minimum limiting value of

$$Z_5 = \left\{ \left[\left(Y_{22}\right)^2 + \left(\frac{X_0}{2}\right)^2 \right]^{\frac{1}{2}} + \frac{B/2}{\sin \alpha_f} - Y_{23} \right\} \tan \alpha_f , \qquad (24)$$

$$0^{\circ} < \alpha_f < 90^{\circ} ,$$

where:

Y_{22} = the horizontal distance (as measured parallel to the length dimension of the vehicle) from the turret axis of rotation to the point (on the front upper hull) defining the Z_4 dimension,

X_0 = the overall vehicle width,

B = the estimated outside diameter of the main armament tube in the region in which it (the tube) comes closest to interfering with the upper front and rear sections of the hull as the turret traverses with the gun tube at the maximum of the depression angles α_f and α_r,

α_f and α_r = the desired maximum depression angle of the main armament tube over the front and rear of the hull, respectively, and

Y_{23} = the horizontal distance from the turret axis of rotation to the trunnion center line.

Using the same argument in regard to the rotation of the main armament tube over the hull rear deck at depression angle α_r, the Z_{13} dimension can approach a minimum value of

$$Z_{13} = \left\{ \left[\left(Y_{24}\right)^2 + \left(\frac{X_0}{2}\right)^2 \right]^{\frac{1}{2}} + \frac{B/2}{\sin \alpha_r} - Y_{23} \right\} \tan \alpha_r , \qquad (25)$$

$$0^{\circ} \leq \alpha_r < 90^{\circ} ,$$

where:

Y_{24} = the horizontal distance (as measured parallel to the length of the vehicle) from the turret axis of rotation to the point on the rear upper hull defining the Z_{12} dimension.

For $\alpha_r = 0^o$, equation 25 reduces to $Z_{13} = B/2$.

The horizontal distance from the turret axis of rotation to the trunnion center line, Y_{23}, depends upon both the specific main armament system employed in the design and upon the turret ring diameter. Given the dimensions of the MA system and the turret ring diameter, the vehicle designer may still have some freedom in locating the trunnion center line with respect to the turret ring ball race.

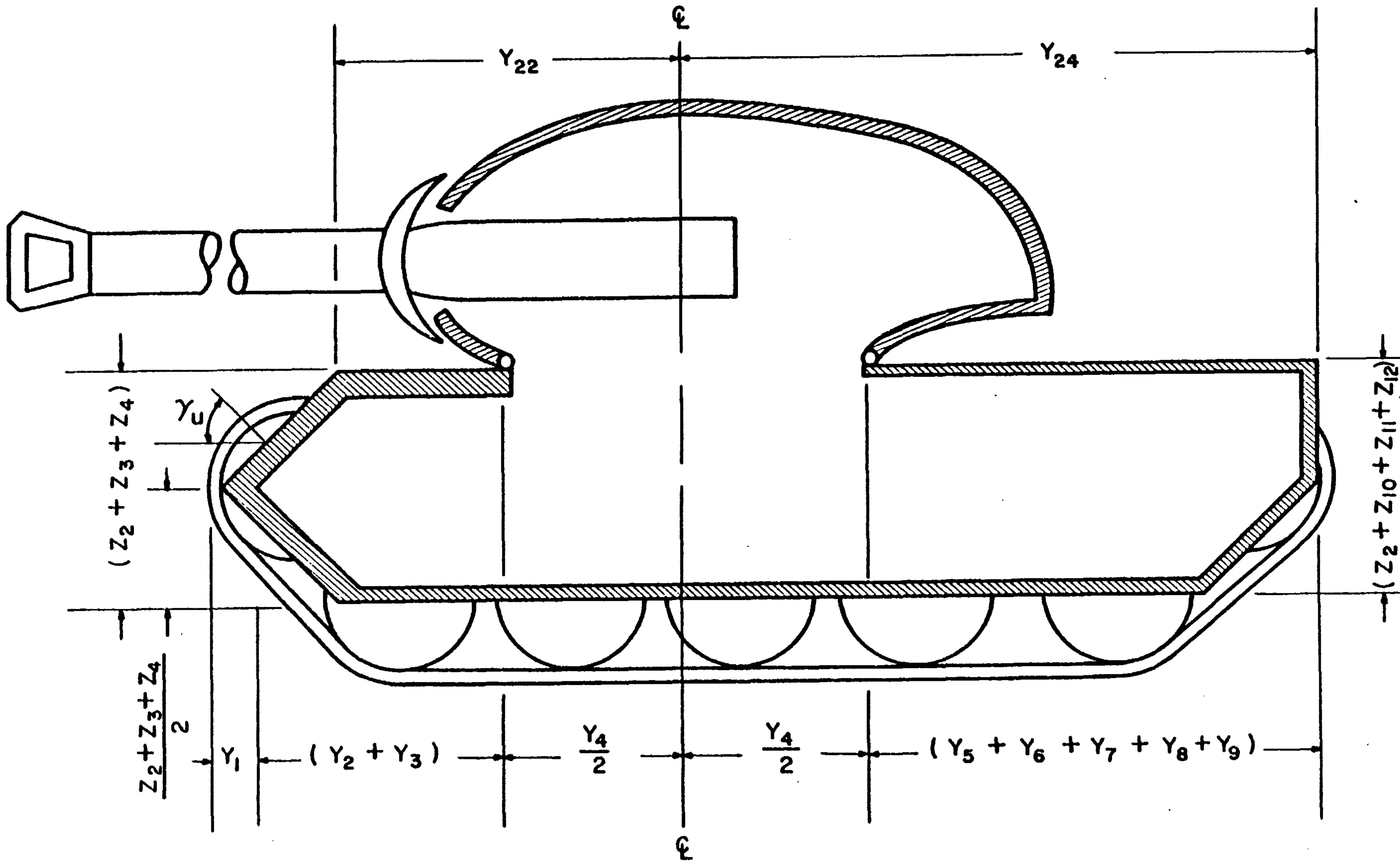
In order to predict Y_{22}, we arbitrarily assume for illustrative purposes that the oblique upper and lower front-hull armor surfaces intersect on a line halfway between the hull bottom and hull upper front-deck outer armor surfaces (see Figure 71), and using our hull-length component predictions we estimate Y_{22} as

$$Y_{22} = Y_1 + Y_2 + Y_3 + \frac{Y_4}{2} - \left[\frac{Z_1 + Z_2 + Z_4}{2}\right] \tan \gamma_u . \qquad (26)$$

In order to predict Y_{24}, we assume the hull rear deck to be a plane surface extending the length of the hull to the rear of the turret. Thus,

$$Y_{24} = \frac{Y_4}{2} + \left(Y_5 + Y_6 + Y_7 + Y_8\right). \qquad (27)$$

The linear "least squares" equation,



Sectional Elevation View of a Conventional Tank Showing the Assumed Hull Geometry Used for Predicting Y_{22} and Y_{24}

Figure 71

$$B = 2.42\,(b) - 4.15\text{, inches,} \tag{28}$$

for predicting an estimate B of the outside diameter of the MA tube was developed from the data of Table 22. In equation 28, b is the MA system bore diameter.

The height Z_6 between the trunnion center line and the ceiling of the turret is predicted by equation 20. However, the observed values of Z_6 in Table 22 may exceed the limiting values for each of these vehicles since the height of the turret ceiling above the trunnion center line may have been determined by crew-accommodation requirements (see discussion on page 313).

The required turret roof armor thickness Z_7 in the area above the breech depends upon the expected enemy threat and the desired degree of protection (see discussion below).

The height Z_8 from the hull inside bottom to the top of the turret platform in the area in which the main armament loader operates depends upon whether or not fuel or ammunition is stored under the turret platform. If fuel or ammunition is stored under the turret platform floor, the Z_8 dimension obviously depends on the quantities stored. For those designs in which no fuel or ammunition is stored in this location the limiting value of the Z_8 dimension might reasonably be taken as the observed value for the M551 vehicle i. e., 7.5 inches .

Prediction of the height Z_9 from the turret platform floor to the inside roof of the turret must take into consideration human factors such as the height of the human body, the techniques by which the MA loader performs his

duties, and the weight of the MA rounds, etc. Observed values of Z_9 for the four vehicles studied fell in the range from 61.5 to 67.5 inches. Apparently, these Z_9 values were acceptable even though the 95 percentile man (in height) is in excess of 72 inches tall. Thus, for the vehicle designs studied in this investigation, crew height must have not been a consideration in determining the height of the turret fighting compartment.

For the three "V"-configuration diesel engines of Table 22, the linear "least squares" equation for predicting engine height[1] Z_{10} from G_{HP} is

$$Z_{10} = .0056\, G_{HP} + 36.62 \text{ inches.} \qquad (29)$$

This linear "least squares" equation is based upon only three data points. Its validity could be improved by including data points from additional engines and transmissions. The additional data could probably be obtained from the engine manufacturers.

The limiting value of Z_{11} depends upon such factors as maintenance accessibility and necessary air flow for cooling the power train. A conservative estimate of Z_{11} would be the minimum value of the observed Z_{11} dimensions in Table 22, i.e., 1.2 inches for the M551 vehicle. It is important to use conservative estimates of vehicle dimensions whenever no other guide lines exist since they are often more representative of the vehicle design state-of-the-art.

[1]The power train height equals the engine height if the engine height exceeds the height of the transmission and if the transmission is coupled to the engine such that the transmission occupies a space within the height of the engine.

As in the case of the hull bottom and front deck armor thicknesses discussed above, the necessary hull rear deck armor thickness Z_{12} depends upon the expected enemy threat and the desired degree of protection.

As stated earlier in this chapter, estimates of vehicle height dimensions based upon the data presented in Table 22 should not be used exclusively of design judgment and new component information (see footnote on page 326).

Gross Vehicle Weight

The gross vehicle weight W_o can be expressed as

$$W_o = W_C + W_G + W_A + W_{AE} + W_S + W_E + W_F + W_H + W_T ,$$

where:

W_C = crew weight (includes crew equipment),

W_G = armament system weight (includes the tube, breech, and recoil mechanisms, etc.),

W_A = ammunition weight,

W_{AE} = weight of accessories and equipment (includes the fire control system, electrical system, radio and electronics equipment, heating and ventilating system, vehicle and engine controls, tools and spare parts),

W_S = weight of the suspension and track (includes the road and idler wheels, torsion bars, shock absorbers, etc.),

W_E = power train system weight (includes the engine, transmission, final drive units, exhaust system, cooling system, etc.),

W_F = fuel system weight (includes the fuel, tanks, pumps, lines, etc.),

W_H = weight of the hull armor, and

W_T = weight of the turret armor.

Estimation equations for predicting the above major component weights have been developed by the Aeronutronic Division of Ford Motor Company (Owen, et al., 1963) and updated by Lockheed Missiles and Space Company (LMSC Report No. B007500, 1965).[1] The relationships obtained in the Aeronutronic study describe the dependence of these component weights on the following performance parameters:

1. crew size,
2. power loading (gross horsepower/gross vehicle weight),
3. cruising range,
4. main armament muzzle energy,
5. number of main armament rounds carried, and
6. mean armor thickness.

These equations, with the exception of the equations for the weights of the hull and turret armor, are recommended for use in estimating gross vehicle weight.[2] A more appropriate method for predicting the hull and turret armor weights is developed in the following sections. Objections to the use of the Aeronutronic and Lockheed equations for prediction of the weights of the hull and turret armor in the Hardware Interaction Model are cited below.

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[1]The component weight estimation equation presented in the Aeronutronic (Owen, et al., 1963) and Lockheed (LMSC Report No. B007500, 1965) reports is classified SECRET. The interested reader is referred to these reports for the details of these prediction equations.

[2]The hull armor also serves as a structural frame for the vehicle; thus, in some publications the hull armor weight is referred to as the hull structure and armor weight.

The Aeronutronic and Lockheed studies relate the armor weight (for vehicles employing steel armor) to the product of the mean armor thickness of the hull and turret and the total armored volume.[1] With their model the total internal hull and turret volume can be predicted from the various individual component and compartment volumes without too much error. However, in order to be meaningful, the mean armor thickness should be selected according to the protection characteristics that are prescribed for the proposed vehicle. The difficulties involved in relating a mean armor thickness to protection requirements are admitted to in the Aeronutronic report (Owen, et al., 1963):

> Because of the complex distribution of armor in the modern tank the use of a mean areal density does not provide a definite measure of the amount of protection afforded.[2]

Thus, it appears to be desirable to have a method of estimating armor weight which explicitly takes into account the different armor thicknesses over the various surfaces of the hull and turret.

Hull and Turret Armor Weight

Total armor weight is considered as the sum of the weights of the various surfaces of the hull and turret. These various surface weights can be estimated on the basis of the vehicle dimensions predicted using models discussed in previous sections.

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[1]The relationship given in the Aeronutronic report and updated in the Lockheed report was developed by "least square" regression techniques using data from numerous American tanks (M3 through M551), six British tanks, five German tanks, and two Soviet tanks.

[2]The armor "mean areal density" measure used here is linearly related to the "mean armor thickness" measure provided that the armor material is homogeneous.

The hull armor is represented by a set of plane surfaces as shown in Figure 72. The various surfaces of the hull are designated in this figure as follows:

Surface 1 ~ hull, upper front
2 ~ hull, front deck
3 ~ hull, rear deck
4 ~ hull, upper back
5 ~ hull, lower back
6 ~ hull, bottom
7 and 8 ~ hull, sides
9 ~ hull, lower front.

The armor weight of the i^{th} hull surface (e.g., the upper front hull, or the hull bottom, etc.) can be estimated by an equation of the form

$$W_{H_i} = A_{H_i} (t_{H_i}) d_H , \qquad (30)$$

where:

W_{H_i} = the armor weight of the i^{th} hull surface (pounds),

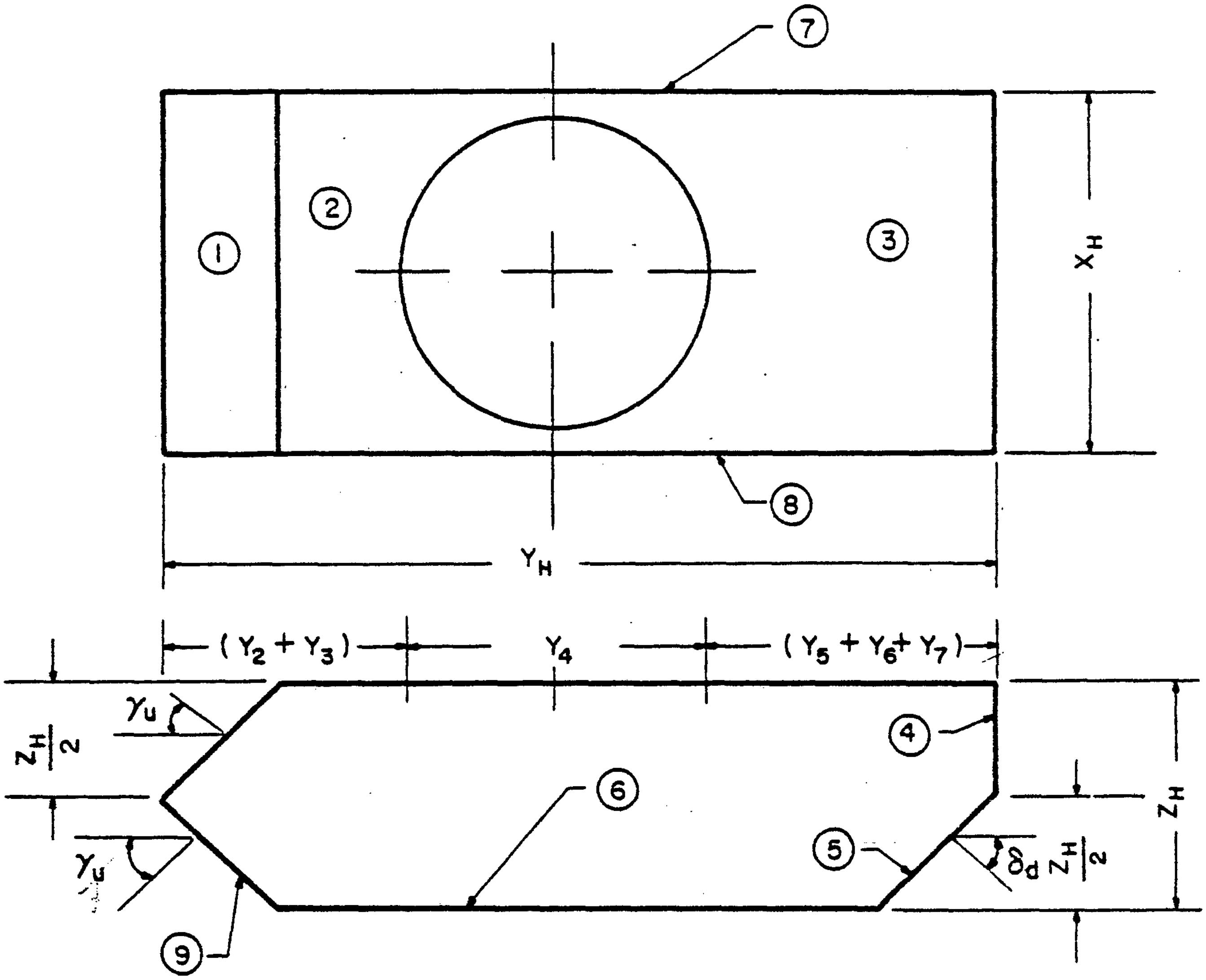
A_{H_i} = the armor area of the i^{th} hull surface (square inches),

t_{H_i} = the mean armor thickness over the i^{th} hull surface (inches),

d_H = the density of the hull armor material (pounds/(inch)^3).

The areas A_{H_i} of the hull surfaces are estimated using the overall dimension prediction models of the previous sections as described below.

The internal width of the hull X_H and the internal length of the hull Y_H, as they have previously been defined, are representative of the size of the hull of the conventional tank. However, estimation of the internal height



The General Hull Geometry Assumed for Hull Weight Calculations

Figure 72

Z_H of the hull requires that an additional assumption be made.

The internal height Z_3 of the front hull and the internal height Z_{10} and Z_{11} of the rear hull are not necessarily equal. For purposes of armor weight estimation, the fact that the hull height is not uniform from front to back is insignificant. Therefore, in this section, we take the inside height of the hull Z_H to be the maximum of these two dimensions. Thus,

$$Z_H = \max \left[Z_3, (Z_{10} + Z_{11}) \right] . \qquad (31)$$

The following equations for computing the weights of each of the hull armor surfaces are based upon the assumed hull geometry illustrated in Figure 72.

<u>Hull, Upper Front Surface Armor Weight W_{Huf}</u>

$$W_{Huf} = A_{Huf} (t_{Huf}) d_H , \qquad (32)$$

where the hull upper front surface area A_{Huf} is approximated as

$$A_{Huf} = X_H \left(\frac{Z_H}{2} \right) \frac{1}{\cos \gamma_u} ,$$

and t_{Huf} is the thickness of the armor on the hull upper front surface.

<u>Hull, Front Deck Surface Armor Weight W_{Hfd}</u>

$$W_{Hfd} = A_{Hfd} (t_{Hfd}) d_H , \qquad (33)$$

where the front deck hull surface area A_{Hfd} is approximated as

$$A_{Hfd} = X_H \left(Y_2 + Y_3 + \frac{Y_4}{2} - \frac{Z_H \tan \gamma_u}{2} \right) - \frac{\pi}{8} (Y_4)^2 ,$$

and t_{Hfd} is the thickness of the armor on the surface of the hull front deck.

<u>Hull, Rear Deck Surface Armor Weight W_{Hrd}</u>

$$W_{Hrd} = A_{Hrd} (t_{Hrd}) d_H , \qquad (34)$$

where the rear deck hull surface area A_{Hrd} is approximated as

$$A_{Hrd} = X_H \left[\frac{Y_4}{2} + Y_5 + Y_6 + Y_7 \right] - \frac{\pi}{8} (Y_4)^2 ,$$

and t_{Hrd} is the thickness of the armor on the surface of the hull rear deck.

<u>Hull, Upper Back Surface Armor Weight W_{Hub}</u>

$$W_{Hub} = (A_{Hub}) (t_{Hub}) d_H , \qquad (35)$$

where the upper back hull surface area A_{Hub} is approximated as

$$A_{Hub} = \tfrac{1}{2} X_H Z_H ,$$

and t_{Hub} is the thickness of the armor on the surface of upper back portion of the hull.

<u>Hull, Lower Back Surface Armor Weight W_{Hlb}</u>

$$W_{Hlb} = (A_{Hlb}) (t_{Hlb}) \cdot d_H , \qquad (36)$$

where the lower back hull surface area A_{Hlb} is approximated as

$$A_{Hlb} = X_H \left(\frac{Z_H}{2 \cos \delta_d} \right),$$

and t_{Hlb} is the thickness of armor on the surface of the lower back portion of the hull.

<u>Hull, Bottom Surface Armor Weight W_{Hb}</u>

$$W_{Hb} = A_{Hb} (t_{Hb}) \, d_H , \qquad (37)$$

where the bottom hull surface area A_{Hb} is approximated as

$$A_{Hb} = X_H \left[Y_H - \frac{Z_H \tan \delta_d}{2} - \frac{Z_H \tan \overset{\gamma}{\cancel{\delta}}_d}{2} \right],$$

and t_{Hb} is the thickness of the armor on the surface of the bottom of the hull.

<u>Hull, Sides Surface Armor Weight W_{Hs}</u>

$$W_{Hs} = A_{Hs} \cdot t_{Hs} \cdot d_H , \qquad (38)$$

where the hull sides (2) armor surface area A_{Hs} is approximated as

$$A_{Hs} = \left[2Y_H Z_H - \left(\frac{Z_H}{2} \right)^2 \left(\tan \delta_d + \tan \gamma_d + \tan \gamma_u \right) \right]$$

and t_{Hs} is the thickness of the armor on the surfaces of the sides of the hull.

<u>Hull, Lower Front Surface Armor Weight W_{Hlf}</u>

$$W_{Hlf} = A_{Hlf} \cdot t_{Hlf} \cdot d_H , \qquad (39)$$

where the lower front hull surface area A_{Hlf} is approximated as

$$A_{Hlf} = X_H \left(\frac{Z_H}{2 \cos \gamma_d} \right),$$

and t_{Hlf} is the thickness of the armor on the surface of the lower front portion of the hull.

Total Hull Armor Weight

The weight of the hull armor (W_H) is then given by the sum of the individual hull armor surfaces

$$W_H = W_{Huf} + W_{Hfd} + W_{Hrd} + W_{Hub} + W_{Hlb} + W_{Hb} + W_{Hs} + W_{Hlf} \,. \quad (40)$$

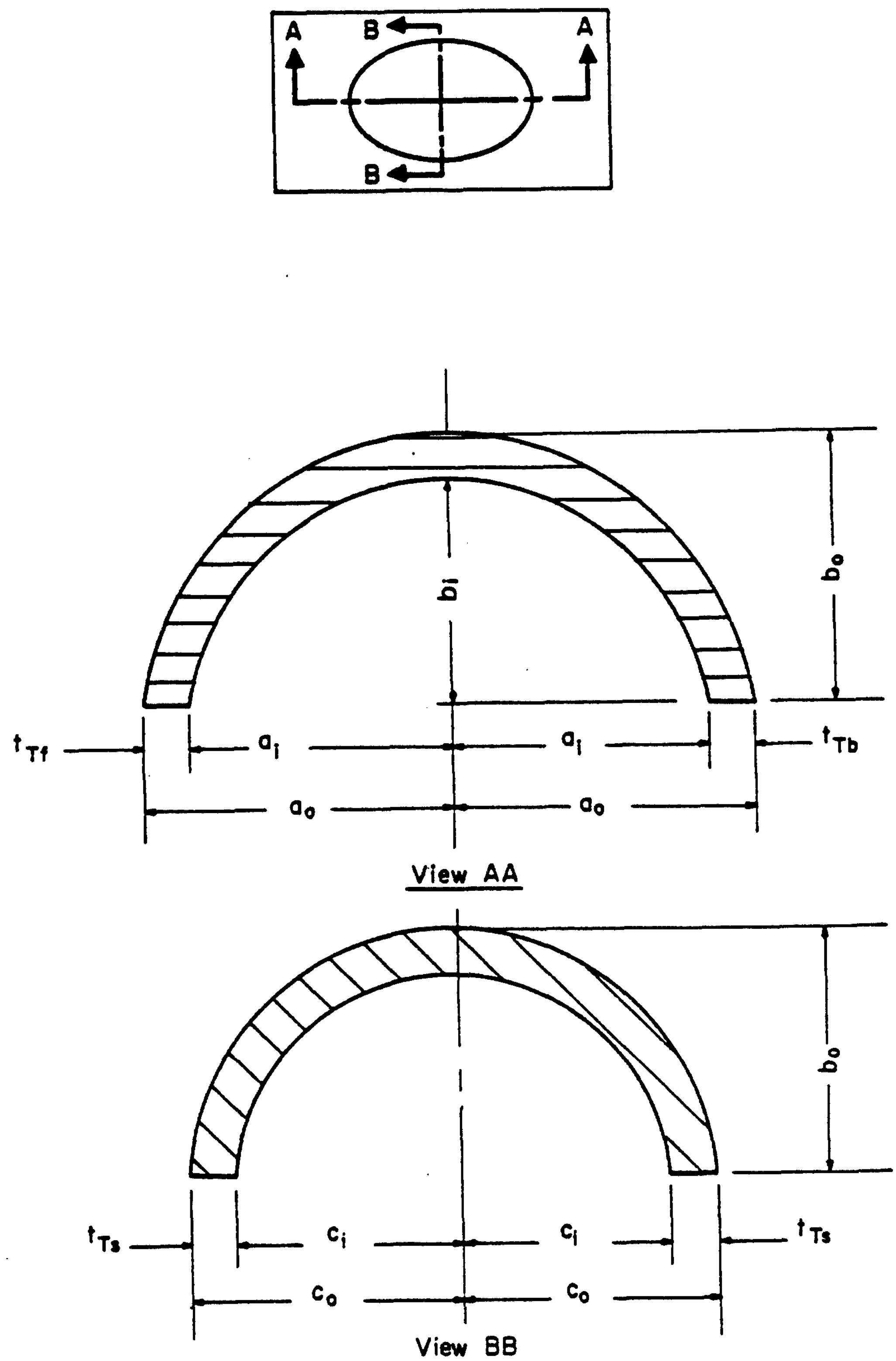
Turret Armor Weight

The inside and outside turret armor surfaces can be represented by a pair of half-ellipsoids as shown in Figure 73. The outside surface of the turret (neglecting the main armament tube, shield, and the tank commander's cupola) is represented by a half-ellipsoid with semi-axes a_0, b_0, and c_0, and the inside surface of the turret armor is represented by a smaller half-ellipsoid with semi-axes a_i, b_i, and c_i (see Figure 73). The approximate weight of the turret armor material of density d_T is then calculated according to the equation

$$W_T = \left[\frac{1}{2} \cdot \frac{4}{3} \cdot \pi \;\; (a_0 b_0 c_0 - a_i b_i c_i) \, d_T \right] + \left[\left(4\pi \, a_i c_i - \frac{\pi Y_4^2}{4} \right) t_{Tu} \, d_T \right], \quad (41)$$

where the $\left[\left(4\pi \, a_i c_i - \frac{\pi Y_4^2}{4} \right) t_{Tu} \, d_T \right]$ represents the weight of the "curled under" part of the turret surface area of mean thickness t_{Tu} (see Figure 71).

The determination of the "best" ellipsoids to represent the inner and outer surfaces of the turret of a proposed vehicle may require detailed design



Sketch Showing Assumed Turret Armor Geometry
for Armor Weight Calculations

Figure 73

analysis. Other, geometrical shapes can be used if appropriate. The internal length of the turret at its base is represented by the ellipsoidal axis $2a_i$; the internal height of the turret above the hull is represented by the ellipsoidal semi-axis b_i; and the internal width of the turret at its base is represented by the ellipsoidal axis $2c_i$.

In order to predict the magnitudes of the dimensions $2a_i$ and $2c_i$, one might assume that they are proportional to the turret ring diameter Y_4 which is predicted by equation 13. The dimensions $2a_i$, b_i, $2c_i$, and the turret ring diameter Y_4, along with the ratios $2a_i/Y_4$ and $2c_i/Y_4$, as measured from the appropriate ATAC "Class and Division" drawings for the four tanks analyzed are shown in Table 23.

Table 23

Turret Dimensional Data for Four Conventional Tanks

Tank Nomenclature	$2a_i$	b_i	$2c_i$	Y_4	$\frac{2a_i}{Y_4}$	$\frac{2c_i}{Y_4}$
M551	99"	24"	95"	77"	1.285	1.23
M60	120"	36"	97"	85"	1.41	1.14
M48	116"	34.5"	97"	85"	1.36	1.14
M41A1	128"	30"	88"	76"	1.68	1.16

The average of the four $2a_i/Y_4$ ratios in Table 23 is 1.434 and the average of the four $2c_i/Y_4$ ratios is 1.18. In the absence of detailed design

information these values could be used to determine approximate values of the internal length and width of the turret at its base. That is, one might predict $2a_i$ and $2c_i$ as follows:

$$2a_i = 1.434\ Y_4$$

and

$$2c_i = 1.18\ Y_4.$$

The internal height b_i of the turret above the hull can be predicted using the overall vehicle height prediction equation previously discussed; that is,

$$b_i = Z_0 - (Z_1 + Z_2 + Z_3 + Z_4 + Z_7). \qquad (42)$$

Given the dimensions $2a_i$, b_i, and $2c_i$, the magnitudes of the dimensions $2a_o$, b_o, and $2c_o$ can be predicted from a knowledge of the various turret armor thicknesses. These turret armor thicknesses are as follows: 1) the turret lower front armor thickness t_{Tf}, 2) the turret lower back armor thickness t_{Tb}, 3) the turret lower side armor thicknesses t_{Ts}, 4) the turret middle top armor thickness t_{Tt}, and 5) the mean thickness of the "curled under" portion of the turret t_{Tu} (see Figure 71). Thus, $2a_o$, b_o, and $2c_o$ are given by

$$2a_o = 2a_i + t_{Tf} + t_{Tb}, \qquad (43)$$

$$b_o = b_i + t_{Tt}, \text{ and} \qquad (44)$$

$$2c_o = 2c_i + 2t_{Ts}. \qquad (45)$$

The weight of the turret armor, W_T, is then predicted by

$$W_T = \frac{2}{3}\pi\left[\left(a_i + \frac{t_{Tf}}{2} + \frac{t_{Tb}}{2}\right)\cdot\left(b_i + t_{Tt}\right)\cdot\left(c_i + t_{Ts}\right) - \left(a_i b_i c_i\right)\right] d_T + \left[\left(4\pi\ a_i c_i - \frac{\pi Y_4^2}{4}\right) t_{Tu}\ d_T\right] \qquad (46)$$

Equation 46 is obtained by substituting equations 43, 44, and 45 into equation 41.

Gross Vehicle Weight

The gross vehicle weight W_o is the sum of the component weights, predicted using the Aeronutronic and Lockheed equations discussed at the beginning of this section, and the hull and turret armor weights W_H and W_T, predicted using the methodology discussed in this section. That is, the gross vehicle weight is given by

$$W_o = W_C + W_G + W_A + W_{AE} + W_S + W_E + W_F + W_H + W_T. \qquad (47)$$

The accuracy of the Aeronutronic gross vehicle weight estimation methodology may be judged through a comparison of the actual gross weights and the predicted weights of the four vehicles discussed in this chapter. These weights are presented in Table 24. The predicted weights of Table 24 were calculated using the actual observed mean armor thickness of the hull and turret and not predicted thickness based upon a qualitative statement of the degree of protection prescribed for the proposed vehicle. Thus, in evaluating these predictions

Table 24

A Comparison of Actual and Predicted Gross Weights Using the Aeronutronic Model for Four Conventional Tanks

Tank	Actual Weight (lbs)	Predicted Weight (lbs)	Percent error = $\frac{\text{Predicted-Actual}}{\text{Actual}} \times 100$
M551	33,460	36,841	+10.01
M60	102,000	103,170	+ 1.50
M48	101,500	94,372	- 7.03
M41A1	52,632	46,331	-12.00

one should consider that they are not dependent on predictions of the mean armor thickness. A subjective method of estimating mean armor thickness for a proposed future vehicle based upon the computed mean armor thicknesses of historical vehicles is presented in the Aeronutronic and Lockheed reports.

Typically, the combined weights of the hull and turret armor account for 30 to 50 percent of the gross vehicle weight, thus a moderate error in the weight prediction of the hull and turret armor may have a significant effect on the gross vehicle weight prediction.

No claim is made here concerning whether or not the methodology for predicting the hull and turret armor weight is more accurate than that presented in the Aeronutronic report. However, the methodology presented here is somewhat more explicit in that it considers the thicknesses of the armor on each of the various surfaces directly.

In the section which follows, some of the common performance measures related to the vehicle size and weight are discussed with reference to their prediction or the constraints they place on overall dimensions.

Performance Measures Related to Vehicle Size and Weight

The design of tank vehicles must conform to various restrictions and requirements that limit certain features of the completed vehicle. These restrictions and requirements which affect dimensional, as well as operational, aspects of the vehicle have been standardized to the point that they are included in Army Regulations (AMCP 706-355, 1965). These requirements have resulted from such considerations as: the need for unrestricted transportability of the vehicle by road, rail, air, and seagoing vessels; the need for standardization to simplify supply and maintenance problems; mobility requirements under adverse conditions of terrain and climate; and certain other theoretical and empirically determined military requirements associated with the performance of the vehicle.

As noted in the introduction to this chapter, the Hardware Interaction Model was developed to assist military planners in judging the relative feasibility of a proposed set of performance requirements relative to a selected set of major vehicle components. In this section, the following design restrictions and performance requirements are discussed:

1. average ground pressure (lbs/in^2);
2. weight load distributed per linear foot of ground contact (lbs/ft);

3. ratio of track-ground contact length, Y_{gc}, to the tread (which is defined as the transverse distance between track centers, $X_0 - X_4$) (dimensionless ratio);

4. maximum trench-width crossing capability (inches); and

5. maximum speed (power limited) over various percent grades (mph).

Values of the above measures associated with a proposed vehicle design can be estimated using the overall dimension and gross weight estimation equations (discussed in the previous sections) in conjunction with certain component dimensions and vehicle characteristics.

Average Ground Pressure

The average ground pressure P is defined as the gross weight of the vehicle divided by the total ground contact area of the tracks; that is,

$$P = \frac{W_o}{2X_4 \quad Y_{gc}} . \tag{48}$$

The maximum allowable ground pressure for heavy tracked vehicles is 12.5 lbs/in^2 (AMCP 706-355, 1965); however, average ground pressures of 6 to 8 lbs/in^2 are considered to be more desirable.

For a specified maximum allowable ground pressure P_{max} it follows that the individual track width X_4 must satisfy the inequality[1]

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[1]Obviously, the gross vehicle weight W_o depends on the size of the suspension system (including the track width X_4). Thus, in order to determine X_4, as well as W_o and P, it would be necessary to go through an iterative procedure. Since the suspension system typically represents approximately 20 to 25 % of the gross vehicle weight, only a few iterations should be required for convergence.

$$X_4 \geq \frac{W_o}{2P_{max} \cdot Y_{gc}} \quad . \tag{49}$$

Weight Load Distributed Per Length of Ground Contact

In addition to the maximum allowable average ground pressure requirement, the weight loading per foot of track ground contact length must be regulated to control the vehicle's weight distribution on roads and bridges. The distributed load per linear foot of ground contact is obtained by dividing the gross vehicle weight in pounds, W_o, by the ground contact length in feet, Y_{gc}. The maximum permissible distributed load is determined from Army regulations as follows (Detroit Arsenal, 1954):

For $W_o \leq 60,000$ lbs

$$\frac{W_o}{Y_{gc}} \leq 3000 + 0.06\,(W_o - 8000), \text{ lbs/ft} \cdot \tag{50}$$

For $60,000 \leq W_o \leq 160,000$ lbs [1]

$$\frac{W_o}{Y_{gc}} \leq \frac{20,000 \,.\, W_o}{160,000 + W_o} \quad , \text{ lbs/ft} \,. \tag{51}$$

Equations 50 and 51 for maximum permissible distributed weight can be solved for Y_{gc} as follows:

---

[1] The maximum permissible weight of a tank, based upon the capacity of U. S. highway bridges of the heaviest classification, is 160,000 lbs. (Detroit Arsenal, 1954).

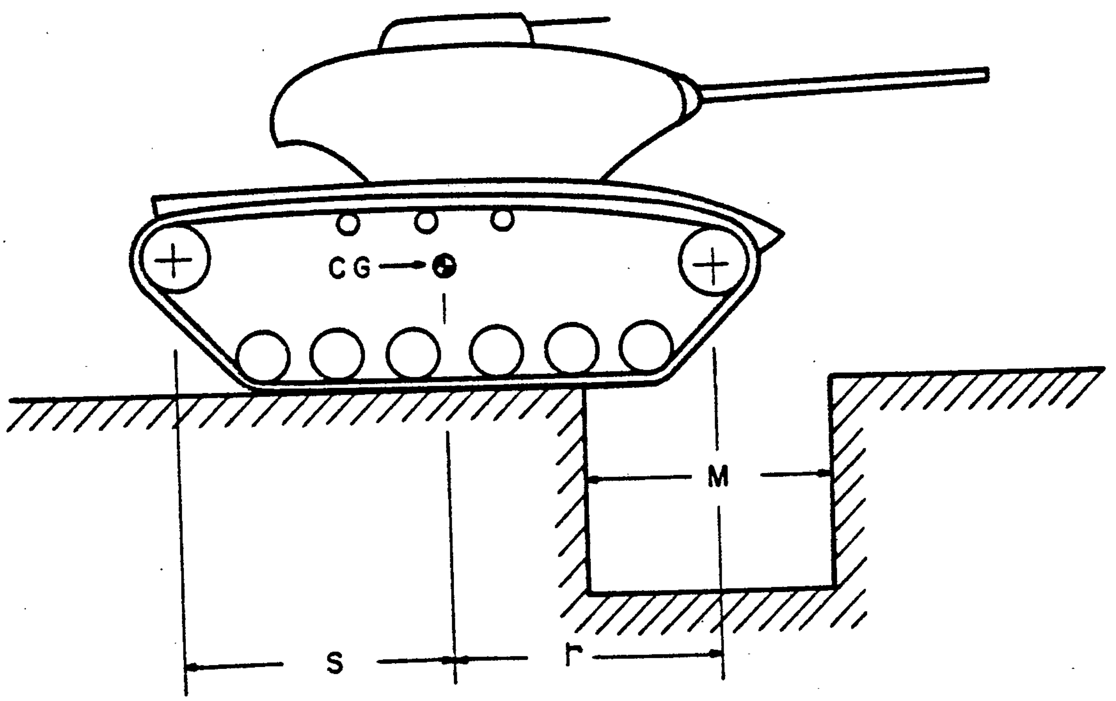
$$Y_{gc} \geq \begin{cases} \dfrac{12\,W_o}{3000 + 0.06(W_o - 8000)}, & W_o \leq 60{,}000 \text{ lbs} \\[2ex] 96 + \dfrac{W_o}{20{,}000}, & 60{,}000 \leq W_o \leq 160{,}000 \text{ lbs.} \end{cases} \tag{52}$$

Ratio of Track-Ground Contact Length to Tread

The steering characteristics of a tracked vehicle are affected by the ratio of the track-ground contact length Y_{gc} to the tread $X_0 - X_4$. When this ratio becomes less than unity, that is, when Y_{gc} is less than $X_0 - X_4$, steering becomes relatively unstable, and when the ratio of Y_{gc} to $X_0 - X_4$ approaches the value of 2, steering imposes excessive power demands (Detroit Arsenal, 1954). The values of $Y_{gc}/(X_0 - X_4)$ usually used are between 1.25 and 1.69 (Detroit Arsenal, 1954). For example, the following $Y_{gc}/(X_0 - X_4)$ ratios apply to each of the tanks discussed in this chapter: 1.51 for the M551, 1.45 for the M60, 1.37 for the M48, and 1.21 for the M41A1.

Maximum Trench Width Crossing Capability

The maximum trench width crossing capability of a tracked vehicle is determined by the length of the hull and the spatial relationship between the suspension system and the hull. We assume that the vehicle crosses the trench horizontally in essentially a static manner; that is, it does not leap the trench by virtue of its momentum. Figure 74 illustrates a tank approaching a trench of width M. In order for a vehicle to be capable of crossing this trench, both



Tank Crossing Trench

Figure 74

the horizontal distance r from the center of the front idler to the vehicle center of gravity CG, and the horizontal distance s from the CG to the center of the drive sprocket must exceed the trench width M;[1] that is, both the conditions $r \geq M$ and $s \geq M$ must be satisfied. Thus, with respect to trench crossing ability, the most desirable position of the vehicle CG is half-way (horizontally) between the idler and drive sprocket center lines. It should be noted, however, that, since the suspension system is elastic, after one of the road wheels progresses beyond the front edge of the trench, the tank front hull will begin to swing down (Gruzdev, 1944). Thus, the true maximum trench crossing capability will be slightly less than that suggested above, i.e., r or s whichever is smaller.

If the vehicle CG is located half-way between the idler center line and the drive sprocket center line, then

$$M_{max} \cong \frac{r+s}{2}. \qquad (53)$$

Using the overall hull length prediction equation given in this chapter along with the approximation

$$C_1 = \frac{D_1}{2} + T \quad \text{and} \quad C_2 = \frac{D_2}{2} + T,$$

the maximum trench width capability of a proposed vehicle (whose CG is located halfway between its front idler center and its drive sprocket center)

---

[1]A methodology for estimating the vehicle center of gravity location of a proposed design is described in Archambault (1960).

is given by

$$M_{max} = \frac{r + s}{2} = \frac{Y_0 - (D_1/2) - (D_2/2) - 2T}{2} \quad . \qquad (54)$$

Maximum Power-Limited Speeds

The speed capability of a vehicle on a specified grade in a given terrain type can be conveniently summarized in terms of the power loading required. Such a specification necessarily involves assumptions regarding the transmission efficiency and a specification of the motion resistance to weight ratio. As a guide for relating vehicle performance to power loading the following discussion is presented.

The sprocket horsepower SHP required to propel a tank vehicle at a constant speed V miles per hour (assuming no slippage of the tracks on the ground surface) equals the product of the speed and the tractive effort. The tractive effort must equal the motion resistance J, which is composed of rolling resistance (internal friction of the running gear plus resistance to road or terrain), grade resistance (the component of the tank weight which is opposite to the direction of motion), and the air resistance.

If a tank weighing W_o lbs. is climbing a slope of θ degrees at V miles per hour with a rolling resistance of R pounds per ton of tank weight, and if A_N is the cross sectional area of the vehicle in the plane normal to the direction of vehicle velocity, the sprocket horsepower SHP required to propel the tank vehicle is

$$SHP = \frac{5280}{3600} \times \frac{1}{550} \times \frac{W_o}{2000} \times V \times \left[R\cos\theta + 2000\sin\theta + \tfrac{1}{2}\rho V^2 C_D A_N \right]. \quad (55)$$

A conservative value for the drag coefficient, C_D, is $C_D = 1.0$ (AMCP 706-355, 1965), and a representative value for the air density, ρ, is $\rho = .00237$ slugs/ft^3 (for air at sea level at 20° C or 68° F). In the discussion which follows a rolling resistance of 75 lb/ton is assumed.[1]

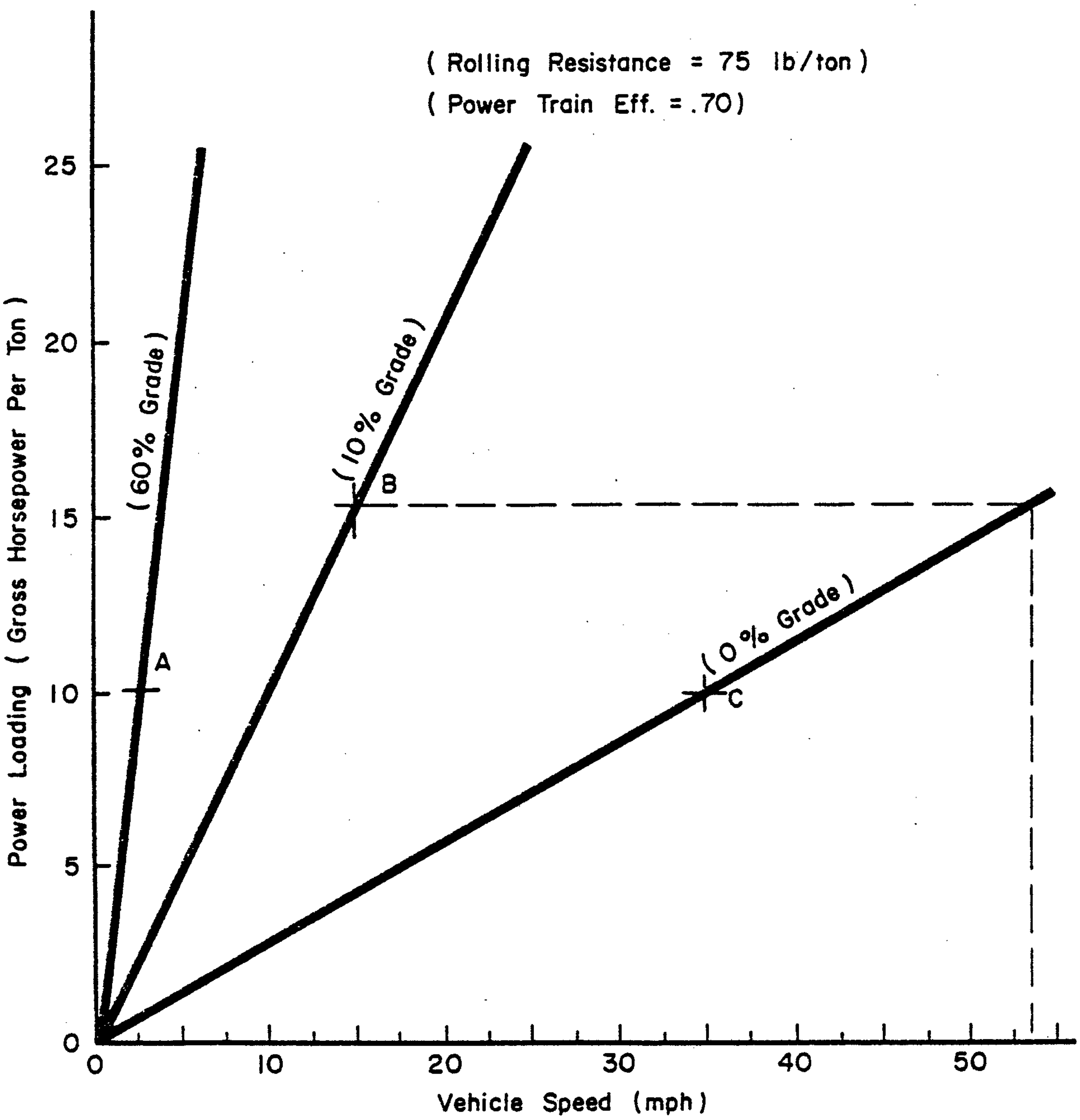
In equation 55, the $\frac{1}{2}\rho V^2 C_D A_N$ term represents the air resistance due to vehicle motion. Since the effect of air resistance is small, i.e., 3.8 lb/ton for the M60 vehicle traveling at its maximum speed of 30 mph, when compared to the assumed rolling resistance value of 75 lb/ton, it is neglected in the following discussion.

Figure 75 is a graphical representation of the relationship between the power loading (gross horsepower per ton gross weight) and the maximum vehicle speed over various grades on paved roads. For this figure, a rolling resistance of 75 lb/ton (see footnote below) and a power train efficiency of 70 percent (i.e., $GHP = \frac{SHP}{.70}$) have been assumed.

Typically, QMR's state maximum speed requirements for 0%, 10%, and 60% grades over various type surfaces. If the maximum speed requirements were specified for paved roads, Figure 75 could be employed in estimating the horsepower requirements of the proposed vehicle. This would be done by

---

[1] Nominal values of the rolling resistance for well designed suspension systems are 75 lb/ton and 60 lb/ton for support roller and flat track suspensions, respectively (Owen, et al., 1963). These values are subtantiated by Aberdeen Proving Ground field test data (Lambert, 1965).



Gross Horsepower per Ton versus Vehicle Speed for
Several Grade Requirements on Paved Roads

Figure 75

determining the necessary power loading associated with each speed-grade requirement and then taking the overall power loading requirement of the vehicle to be the maximum of those associated with each speed-grade requirement. This overall power loading factor must then be multiplied by the estimated gross weight W_o of the vehicle (in tons) to determine the horsepower required. However, the gross vehicle weight W_o depends upon the size and weight of the engine which, in turn, depend upon the gross horsepower. Thus, some iteration is required to determine the engine gross horsepower and gross vehicle weight using the estimation technique described above.

Owen, et al., (1963) give a plot similar to Figure 75, showing the maximum speeds for some past and current combat tank vehicles. In the above reference, it is noted that these quoted maximum speeds are considerably less than those of the 0% grade curve of Figure 75, and several lines of reasoning are presented to explain this discrepancy: 1) tanks are seldom designed for all-out maximum speed, e.g., the engine and transmission may be mismatched such that maximum engine horsepower is not developed at maximum vehicle speed; 2) the maximum speeds quoted are often determined by maximum governed engine speeds; and 3) even though engine speed may not be limited by a governor, other factors, such as induced vibrations, may limit maximum speed to a value less than the maximum power limited speed. However, the observed maximum speeds over grades of 10% or more were found to be in good agreement with the predicted values. Since the maximum speed requirements on level (0% grade) surfaces as well as on specified grades (usually 10%

and 60%) must be met, the power loading is, as shown by Owen, et al., (1963), an adequate measure of the vehicle performance capability in terms of speed and gradability.

In order to illustrate the use of Figure 75 in determining power loading requirements, let us suppose that the speed-grade capability requirements for a proposed vehicle are specified in the QMR as follows:

1. The proposed vehicle must be capable of negotiating a hard surfaced 60% grade at 2.5 mph (see point A in Figure 75).
2. The proposed vehicle must be capable of negotiating a hard surfaced 10% grade at 15 mph (see point B in Figure 75).
3. The proposed vehicle must be capable of achieving a maximum velocity of 35 mph on a level hard surfaced road (see point C in Figure 75).

The power loading required to satisfy all three speed-grade capability requirements of this hypothetical QMR is at point B (see Figure 75). The resulting maximum (power limited) speed over a level paved road for such a vehicle is approximately 53 mph. Since this maximum velocity greatly exceeds the maximum velocity requirement (35 mph) for a level paved road, the military planner or those responsible for writing the QMR may choose to decrease the specified maximum speed requirement on a 10% grade to say 10 mph in which case all three speed-grade requirements would yield essentially the same power loading requirement (reduced to approximately 10.5 GHP/ton from 15.0 GHP/ton at point B--see Figure 75). Actually, the gross horsepower per ton required of the engine would be further reduced since the larger engine associated with the 15 gross horsepower per ton power loading factor would

also weigh substantially more than the smaller engine associated with the power loading factor of 10.5.

Conclusions and Recommendations for Further Research

As noted in the introduction, there is no intention for the work presented in this chapter to be used to generate specific designs of future vehicles. The model's function is primarily to predict system characteristics that could be expected when a given set of new components are assembled according to the present state-of-the-art. It is hoped that the relationships contained in the model can be used as a basis for making more intelligent preliminary estimates of the feasibility of a given set of performance or system characteristics. The potential reduction in lead time that would result from beginning with more feasible QMDO's would seem to justify a careful consideration of this work with respect to possible extension and use by other agencies as well as in the context of its contribution to the Tank Weapon System Study.

Although the model discussed in this chapter is based upon the assumed configuration of an M60 type vehicle, the methodology can be readily extended to new and different design concepts (e.g., the US/FRG or the MBT-70). All that is needed is a general layout, showing the relative positions of the basic components within the hull and turret, and equations for estimating the sizes and weights of these components as functions of scalable independent variables.

The methodology presented in this chapter could be improved by the development of a formal algorithm, for calculating dimensions and gross weight,

which would take into consideration the iterative nature of the vehicle design problem. For example, the size of the powertrain system affects the size and weight of the hull which in turn affect the weight of the suspension system and the amount of fuel necessary for a specified type mission. In addition, the gross weight of the vehicle and the horsepower of the engine (which affects its size and weight) determines the maximum speed of the vehicle. Thus, the determination of the effect of a change in the horsepower (and size and weight) of a vehicle's engine on its mobility characteristics is a complex problem which is best solved using an iterative algorithm.

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This report describes a parametric engineering system definition model developed for use in planning tank-automotive research and development. The model can be used for (1) estimating the performance of a conceptual armored combat vehicle consisting of a specified set of components or (2) "sizing" a vehicle to meet a set of performance specifications. Key elements of the model include a structure for a data base to contain descriptions of components which might be incorporated into future armored

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combat vehicles, (2) a solution algorithm which uses a combinatorial approach to search over alternative combinations of components to find one which meets specifications input by the model user, (3) a variety of engineering relationships and "look-up table" functions for estimating system engineering parameters and performance characteristics, and (4) routines which output a description of the concept vehicle generated by the model.